



# The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes

Brennan D. Less, Iain S. Walker, Nuria Casquero-Modrego, Leo Rainer

2021-11-04

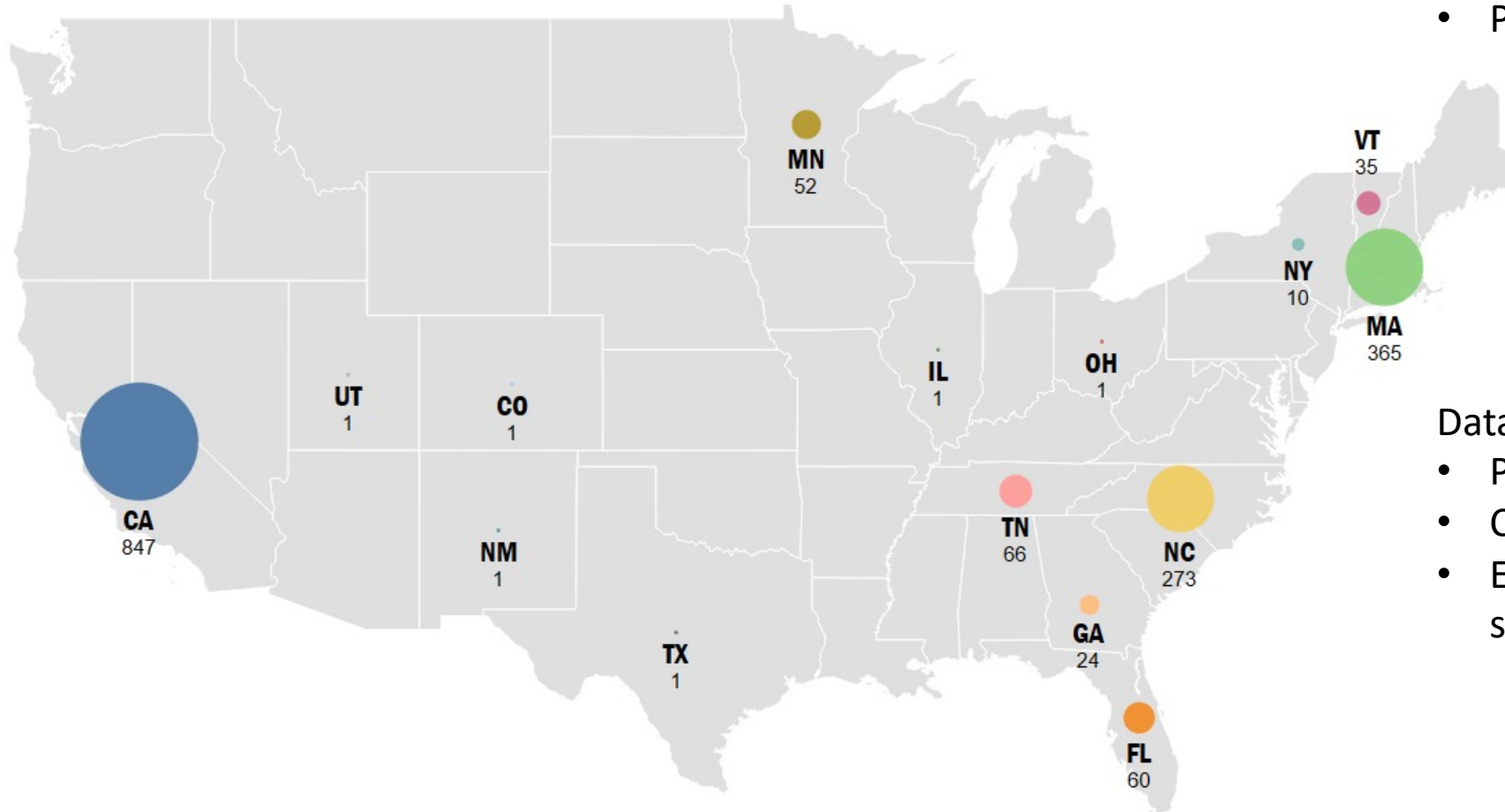


**BUILDING TECHNOLOGY & URBAN SYSTEMS DIVISION**  
Energy Technologies Area

# Database Summary

Sample of convenience:

- Most data voluntarily provided by energy programs
- Paid contributions for 475 homes



Data included:

- Project meta-data
- Costs broken down by measure
- Energy (and calculated CO<sub>2</sub>) savings for whole project

12 Programs

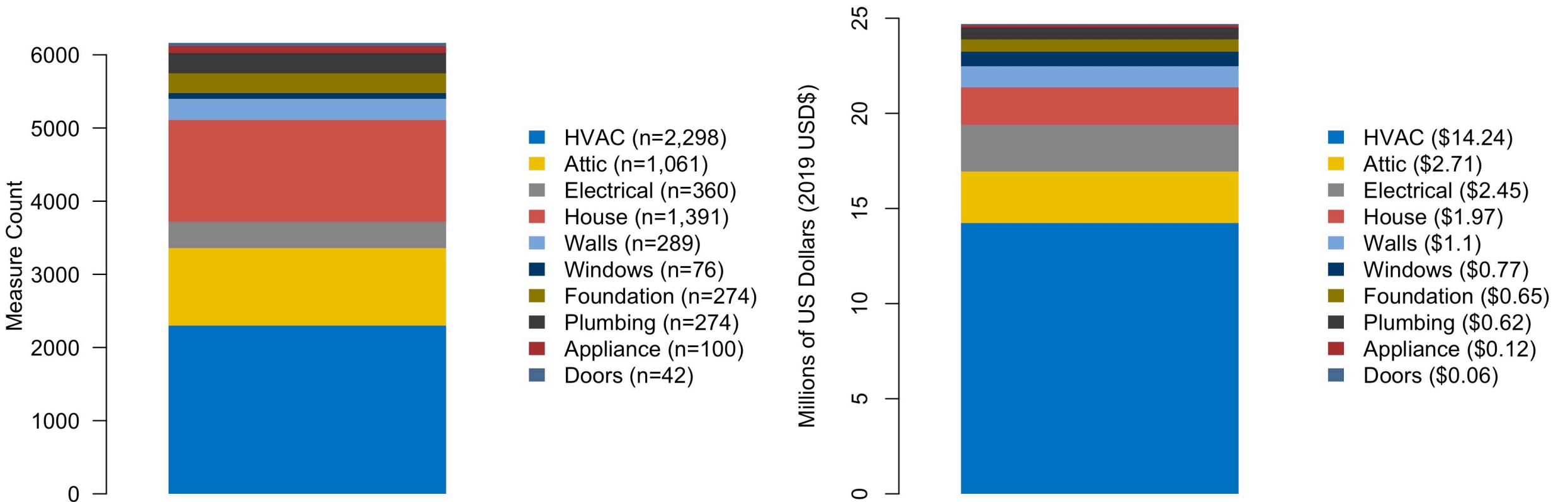
1,739 Projects

10,512 Measures

3,294,946 ft<sup>2</sup>

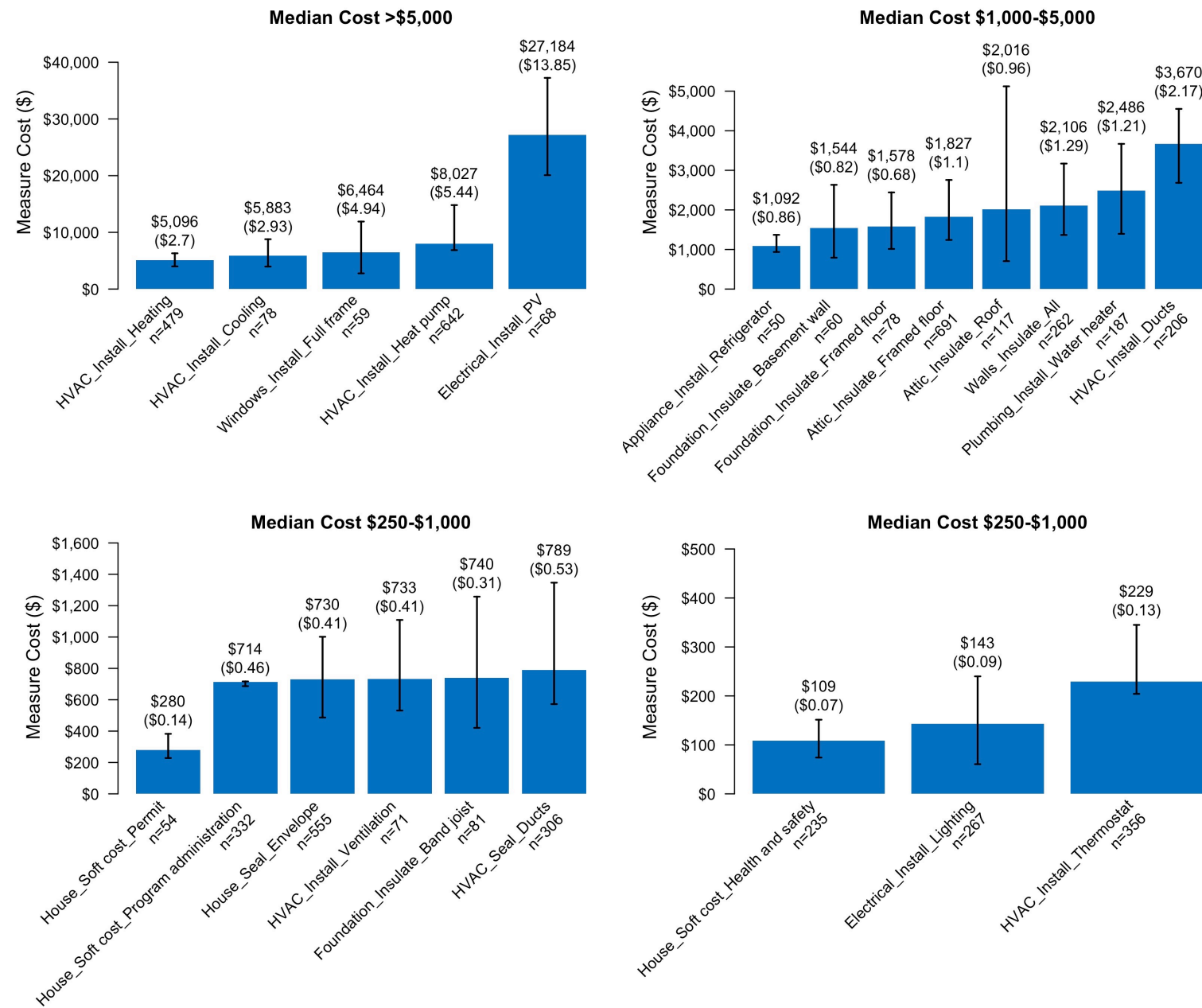
\$24,689,213

# Measure Breakdown



# Costs of Most Frequent Upgrade Measures

Median Total Cost (\$ per ft²)

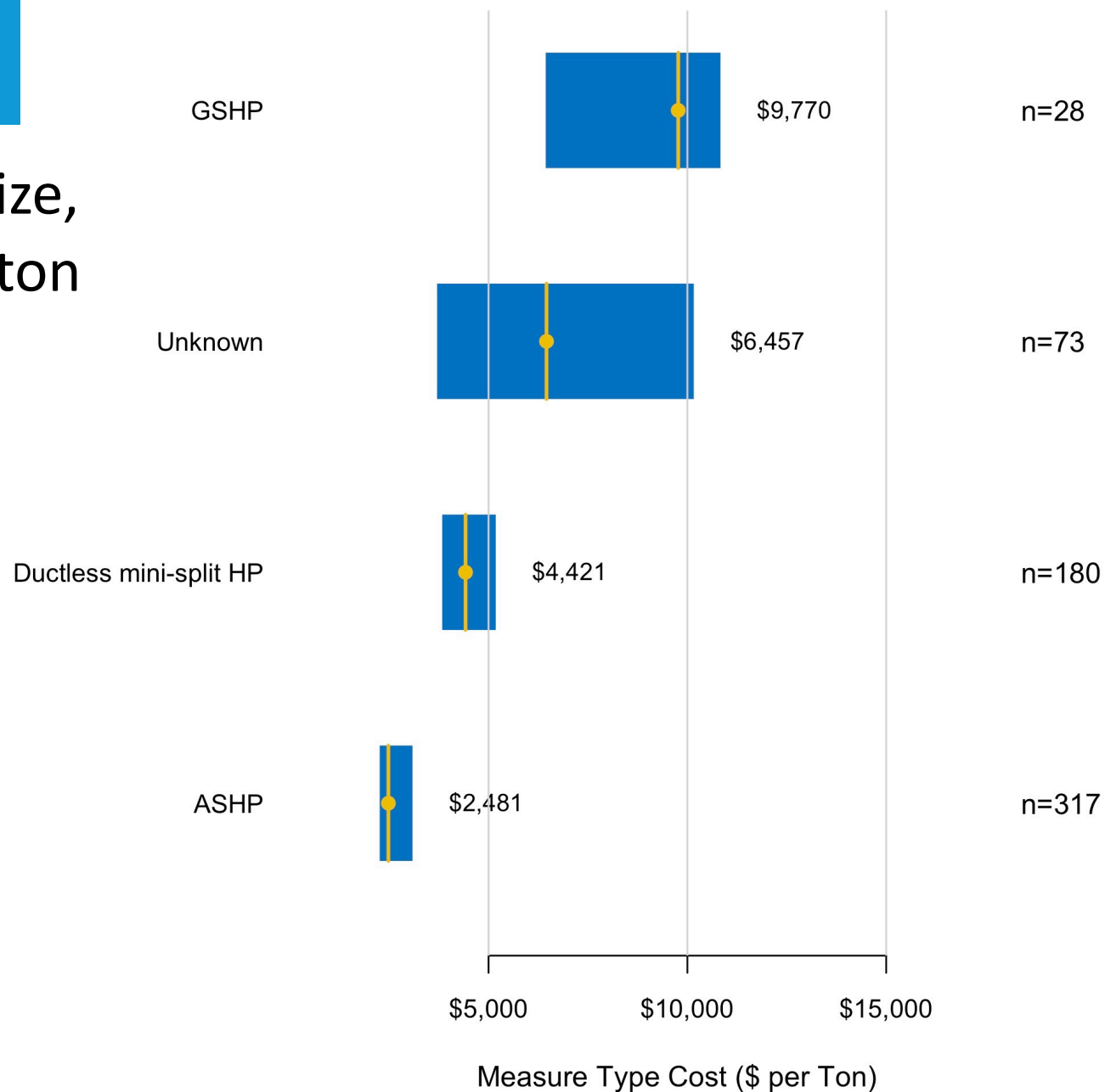




# Heat Pump Costs

Some measures broken down by size,  
for example, heat pump costs per ton

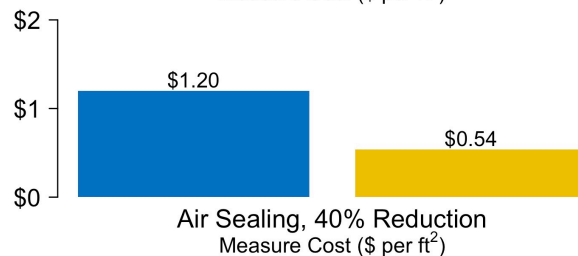
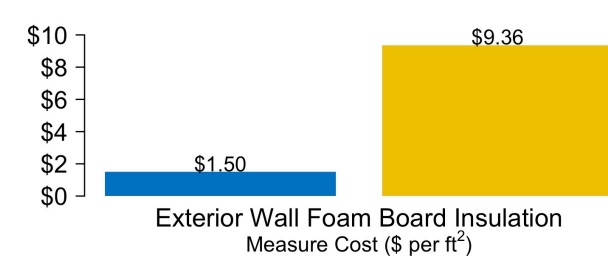
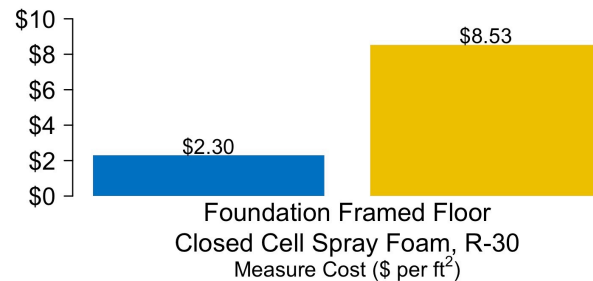
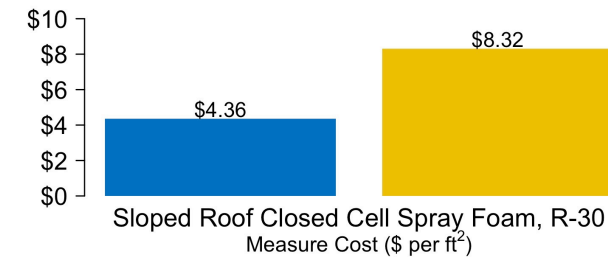
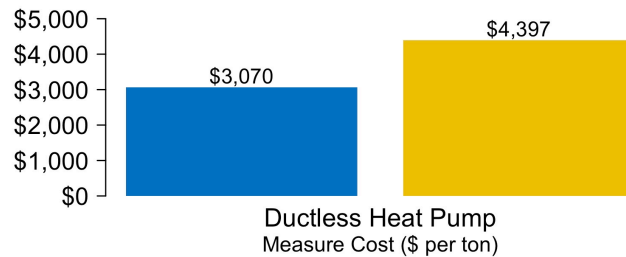
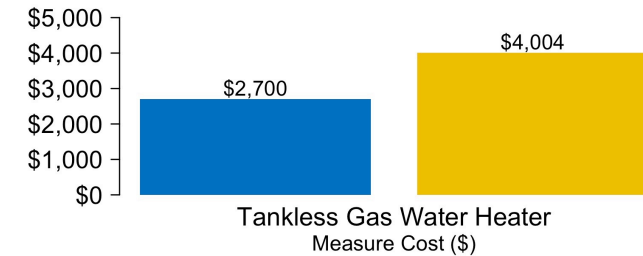
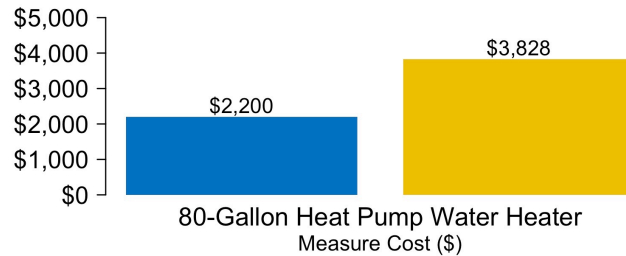
## Heat Pump installation costs per ton



# Comparing Median Measure Costs Against NREL EMDB

Most reported costs  
higher than NREL  
database

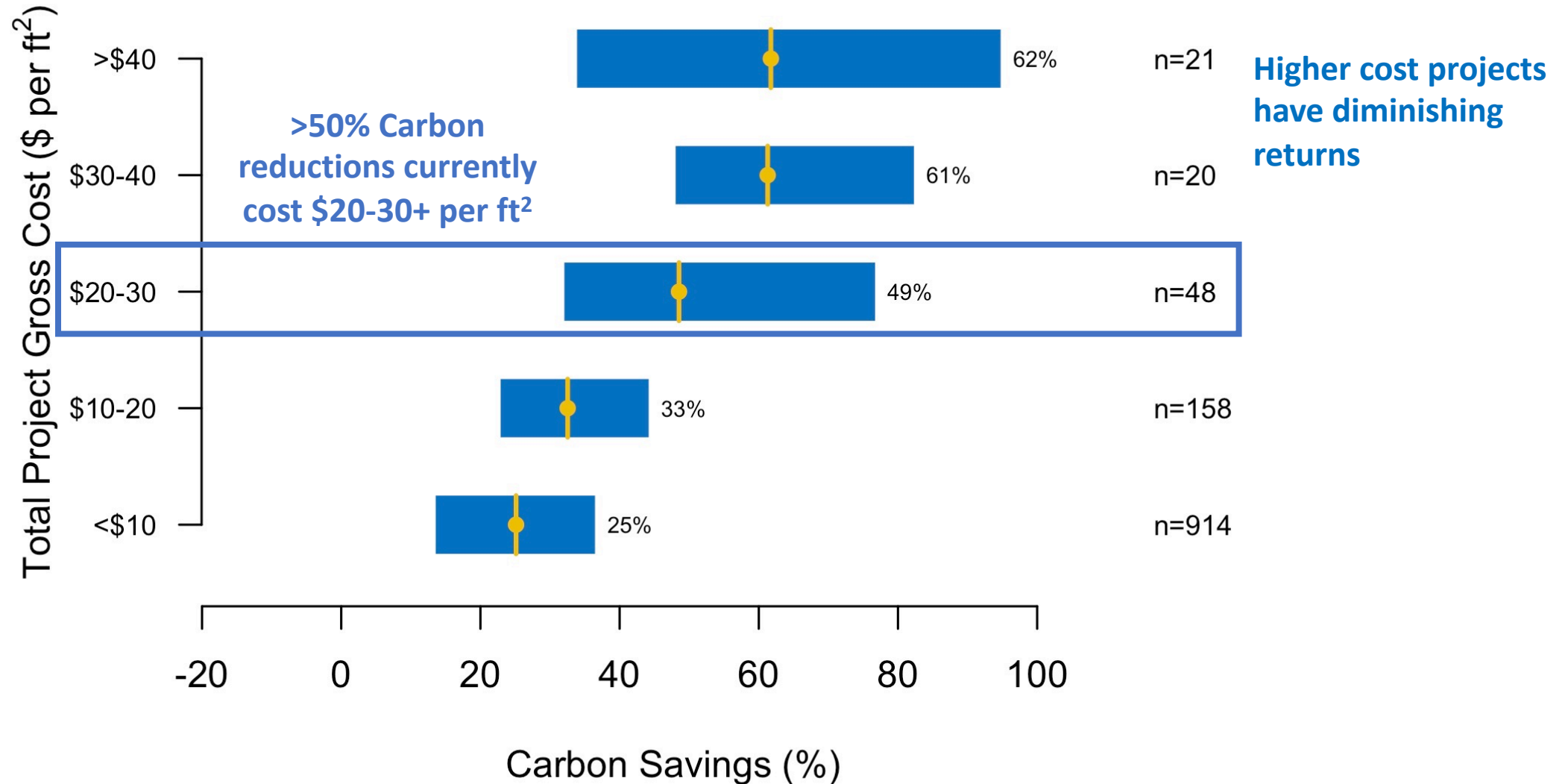
LBNL & NREL  
collaborating to  
update database



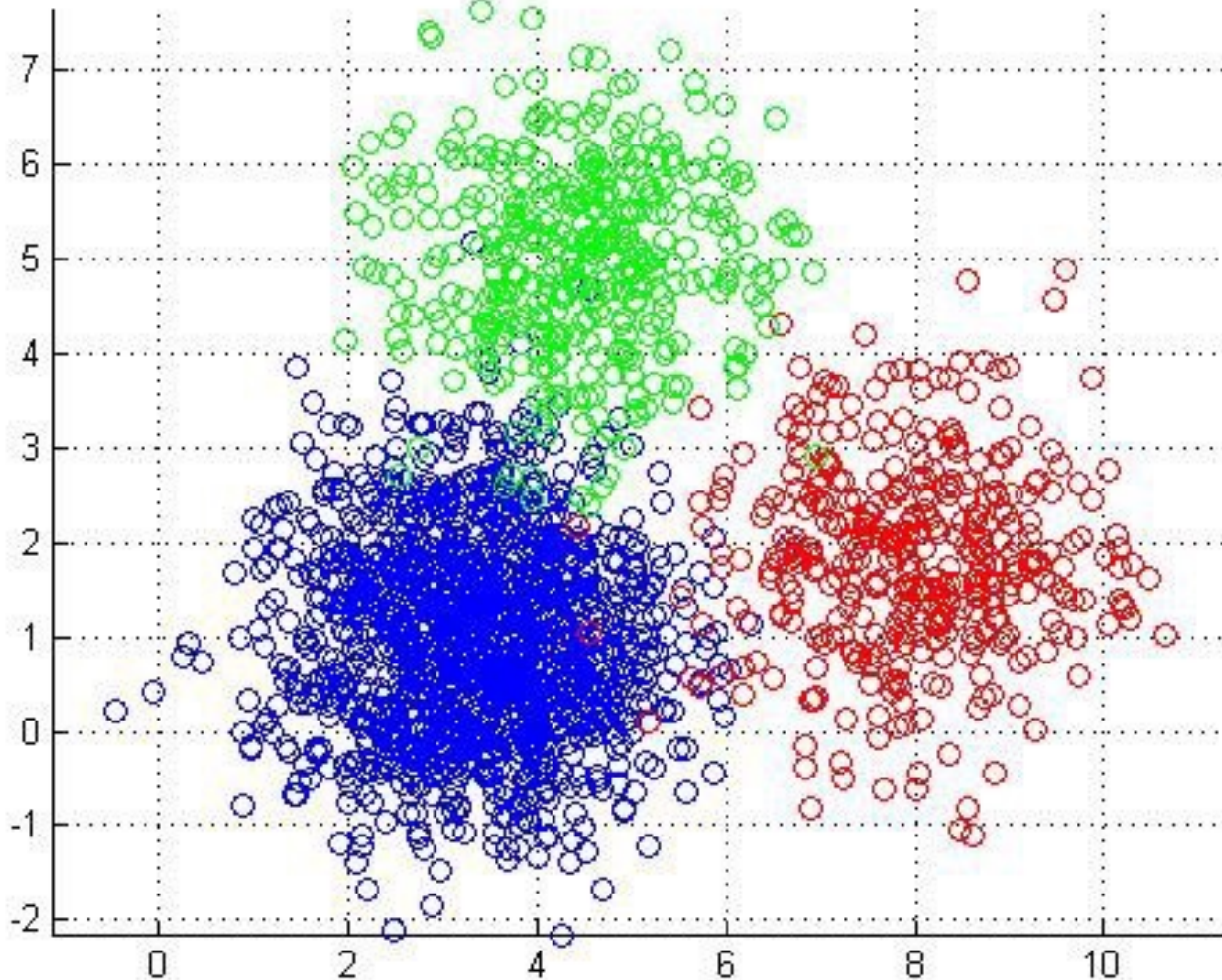
■ NREL Measure Database  
■ LBNL Database

# Project Cost vs. Carbon Savings

How much does it cost to get to 50% savings?



# Clustering Project Types

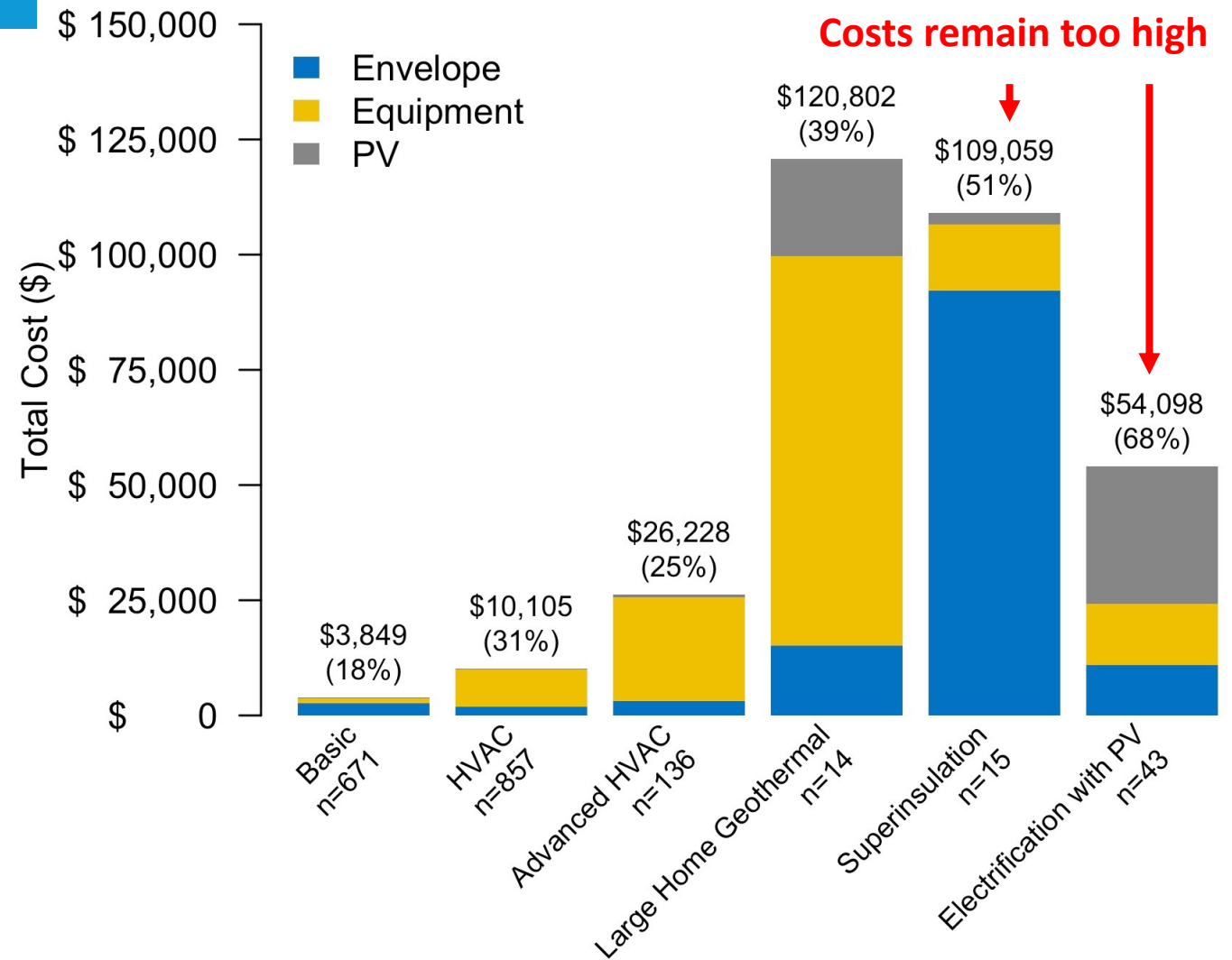


Unsupervised **Machine Learning** approach that groups similar objects such that the objects in the same group are more similar to each other than to objects in the other groups.

Upgrade projects were clustered according to how money was spent.



# Clustered Project Cost Stacks

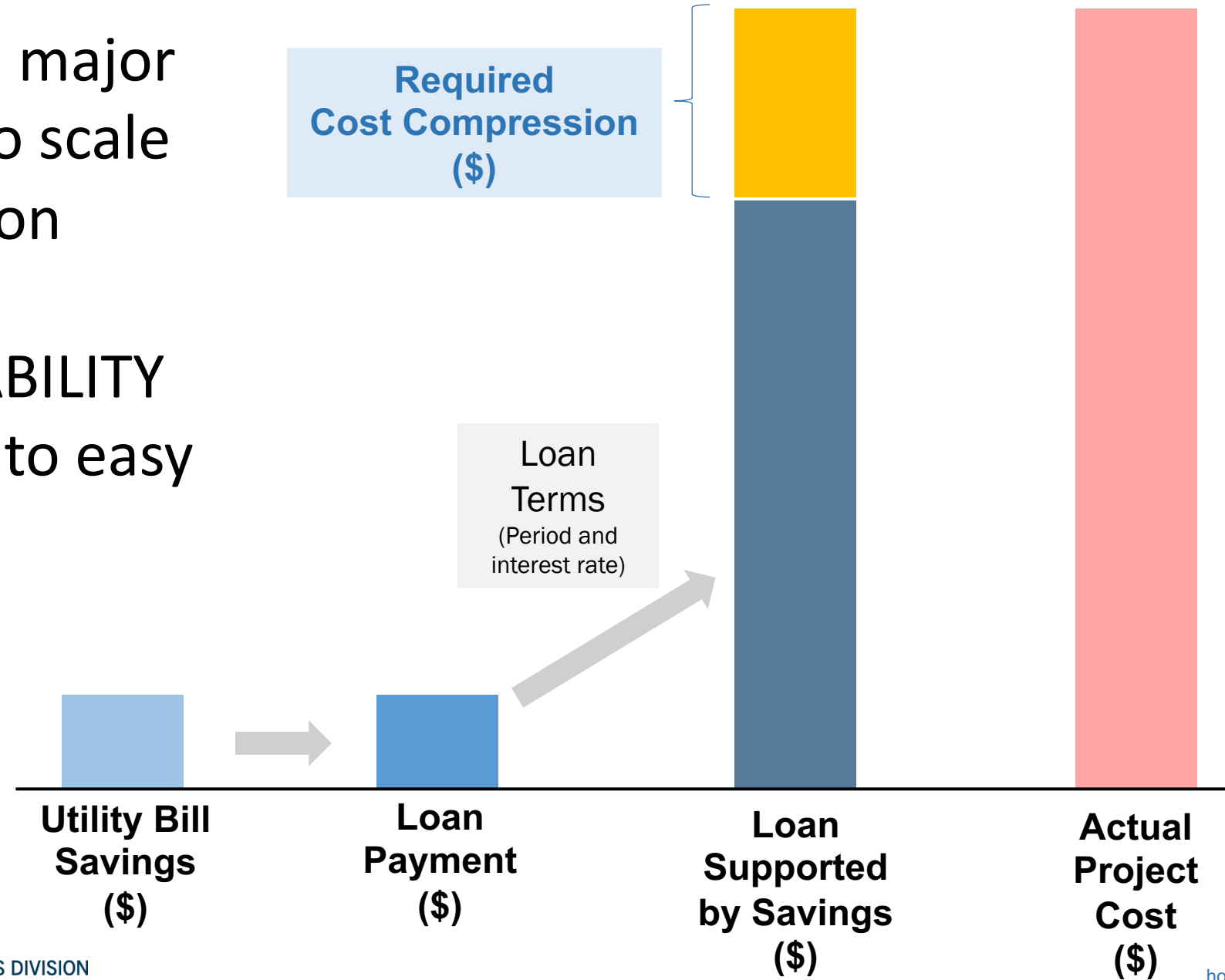


# Affordability, Cash Flow and Cost Compression – Schematic

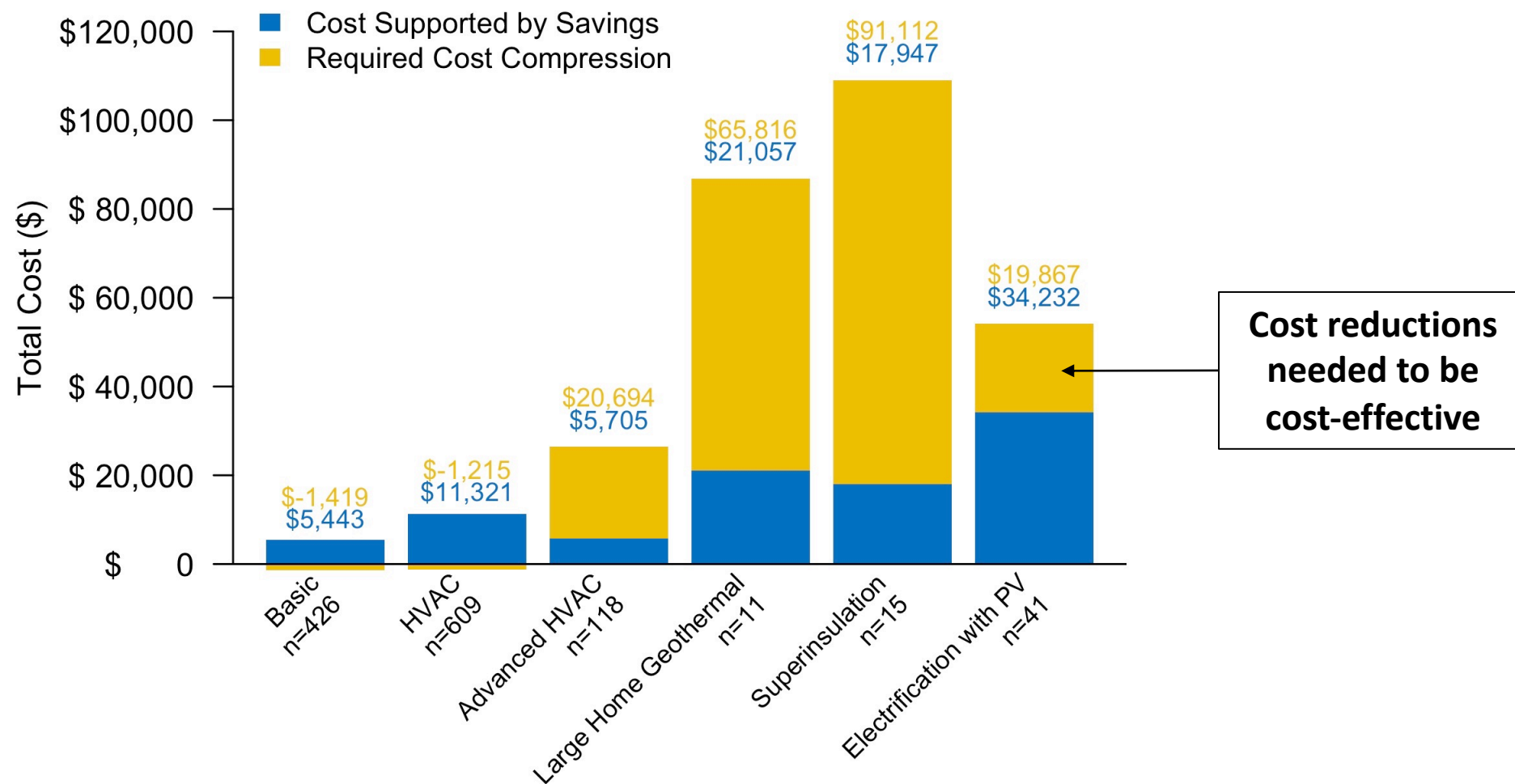
Upfront costs are a major barrier to getting to scale with decarbonization

Focus on AFFORDABILITY

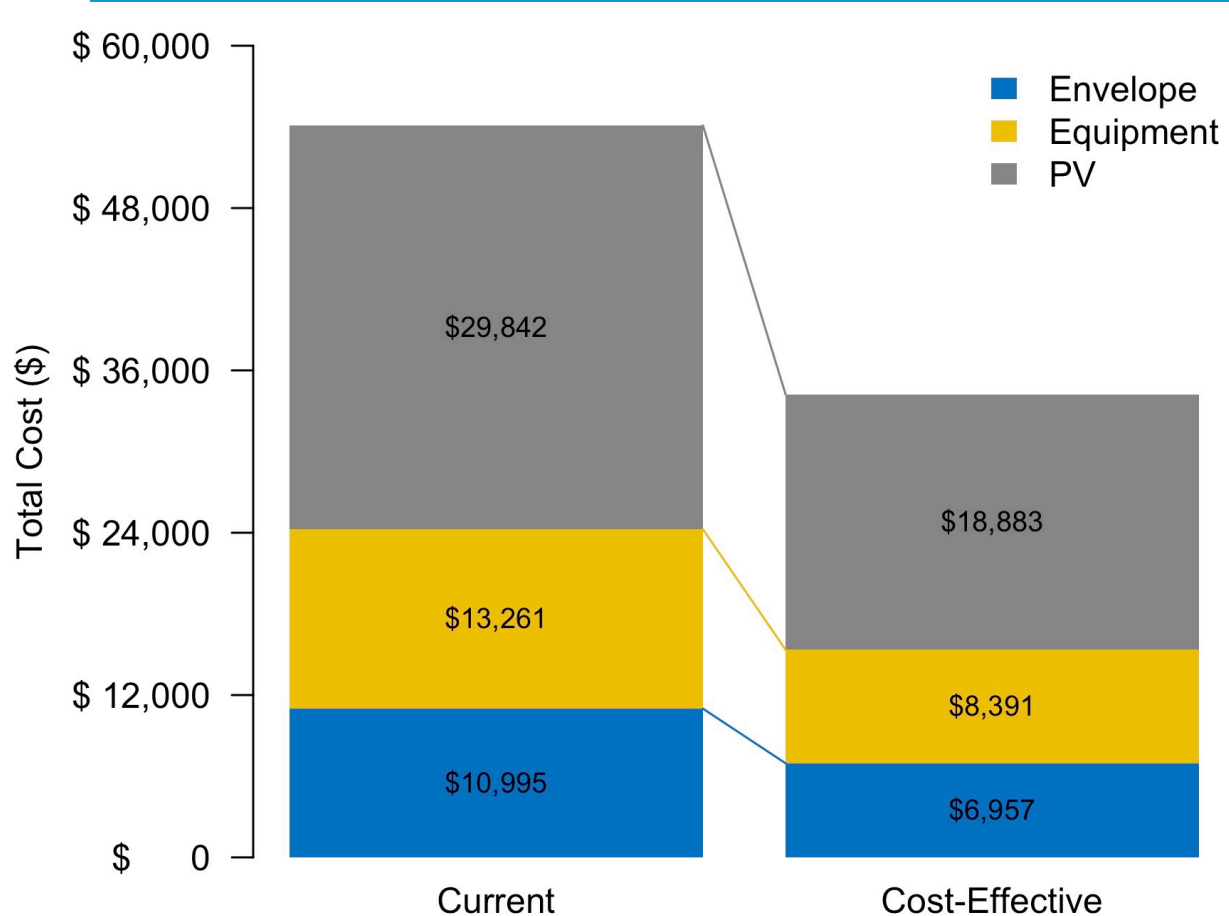
- Requires access to easy financing



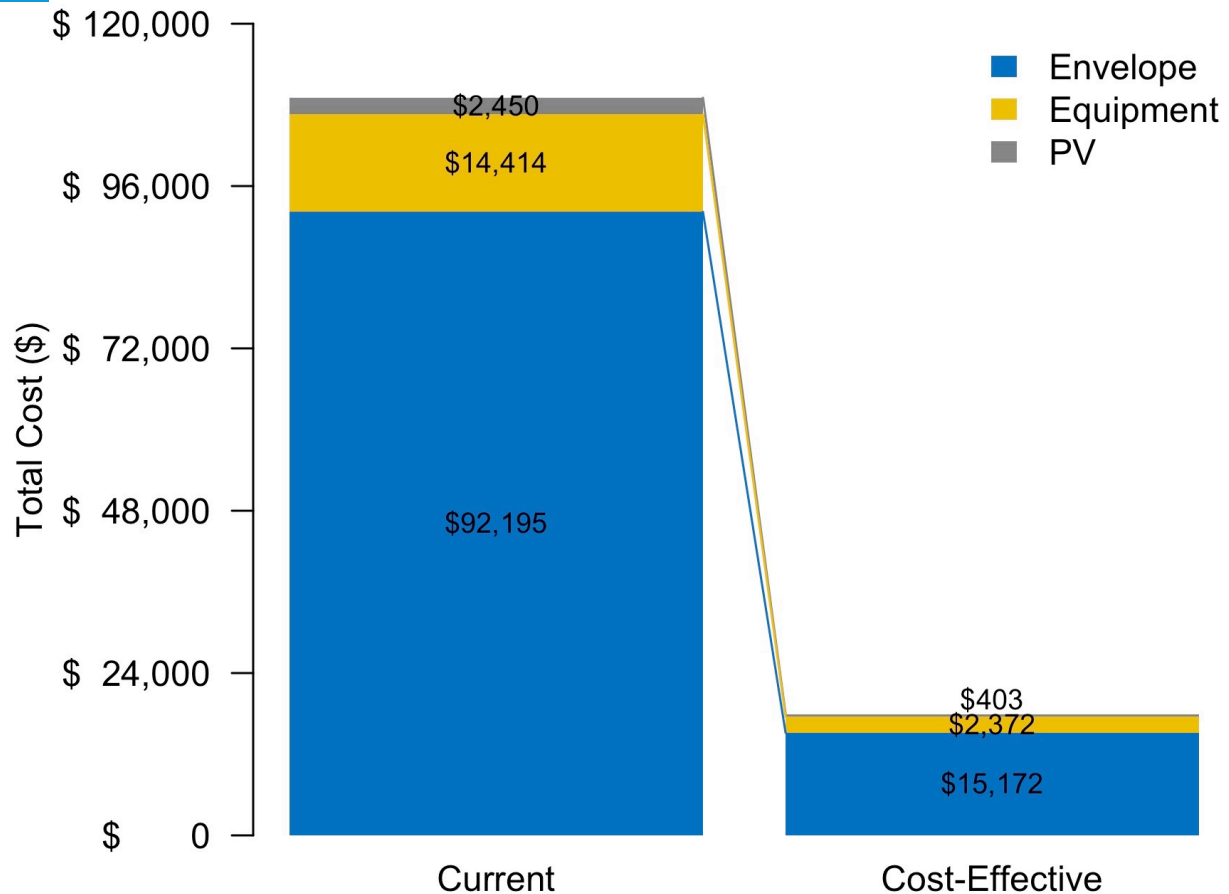
# Clustered Projects Required Cost Compression



# Clustered Projects Saving > 50% Compressed Cost Stacks



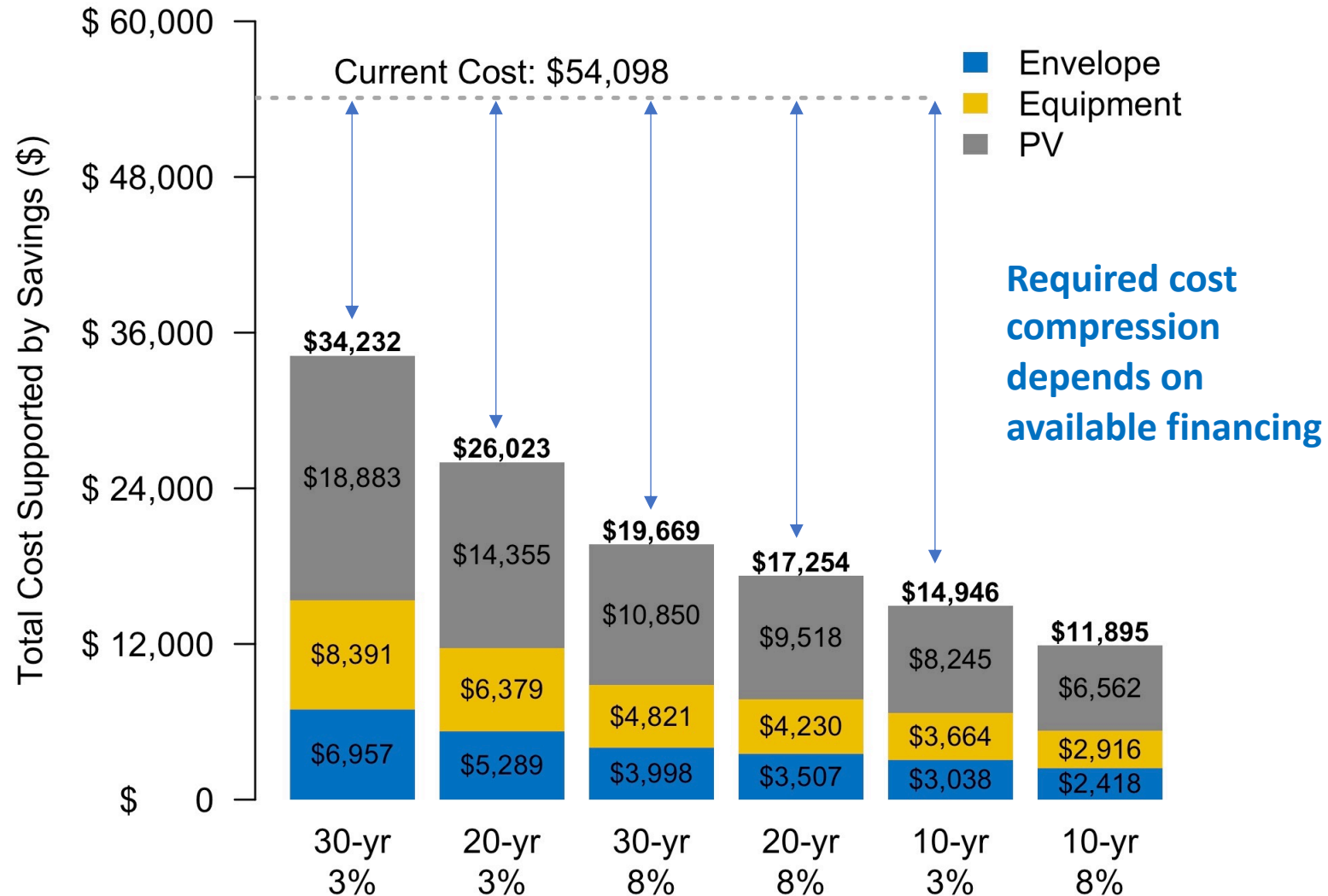
Electrification with PV  
n=43



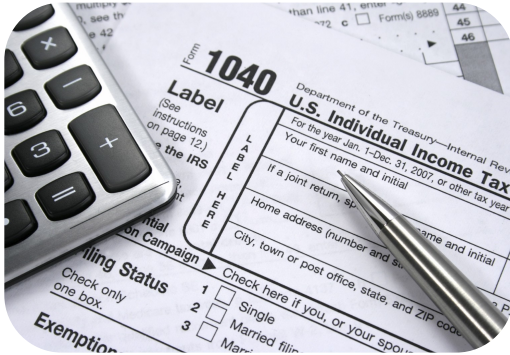
Superinsulation  
n=15



# Clustered Projects Compressed Cost Stacks – Varying Financing Terms



# Cost Compression - Pathways



Rebates and  
Incentives



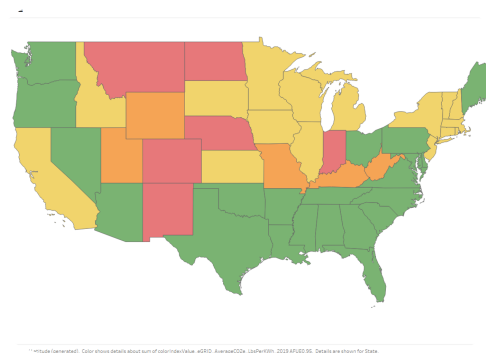
Upgrade Package  
Optimization



Technology  
Innovation



Soft Cost  
Reductions

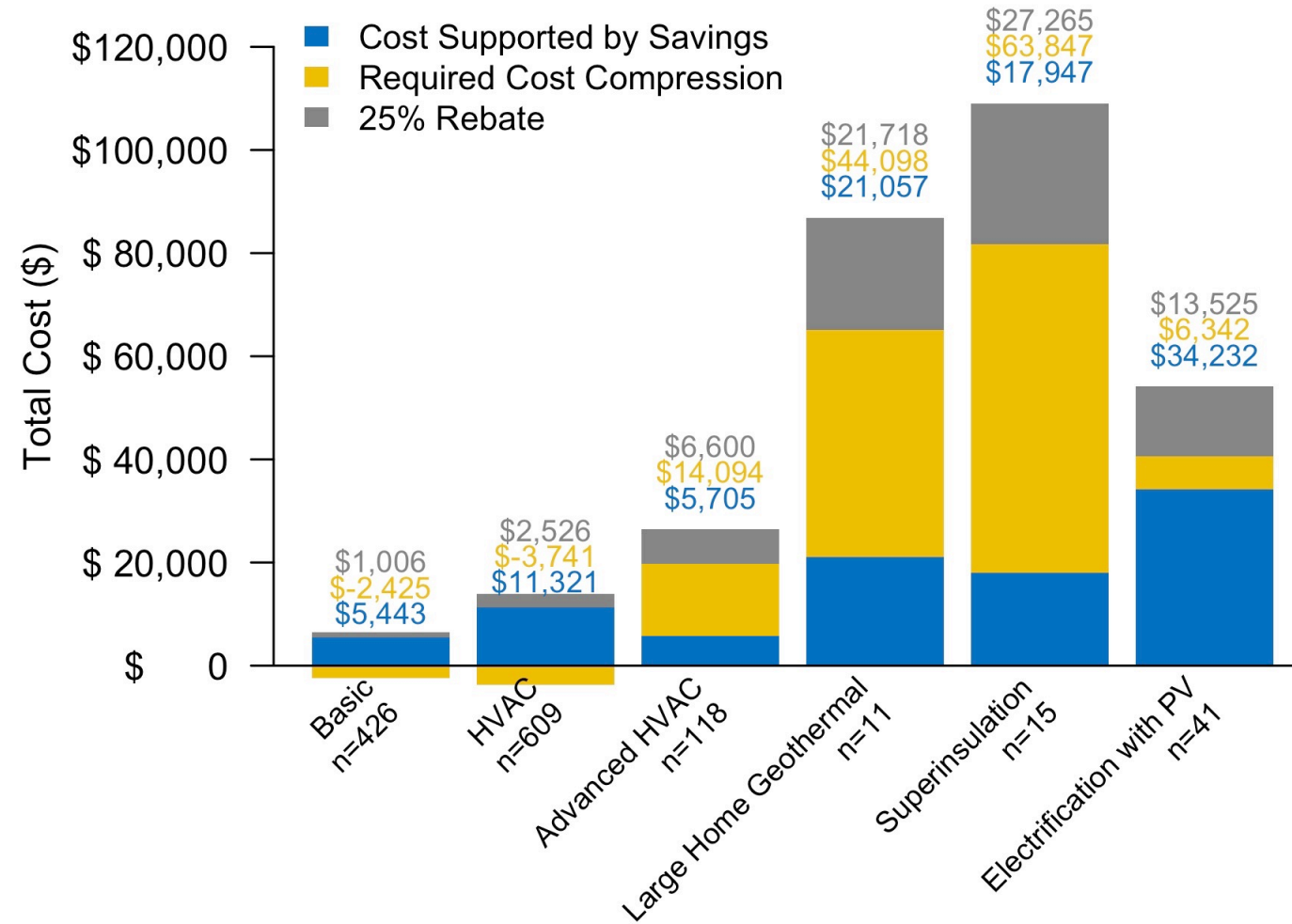


New Metrics



No- and Low-Cost  
Methods

# Cost Compression - Rebates



# Cost Compression – Package Optimization

## Archetypal Upgrade Packages

	Predicted Cost (\$)	Upgrade
None		
Door weather stripping*	\$99	---
Lighting upgrades	\$387	17 units
Low flow faucet*	\$19	1 unit
<b>TOTAL</b>	<b>\$505</b>	<b>\$0.29 per ft²</b>
Weatherization (Wx)		
Attic floor insulation, R60	\$4,402	R-60
Door weather stripping*	\$99	---
Lighting upgrades	\$387	17 units
Seal envelope, typical*	\$831	ACH <sub>50</sub> 13 pre, 8.2 post
Duct seal, typical*	\$849	CFM <sub>25</sub> 329 pre, 97 post
Low flow faucet*	\$19	1 unit
<b>TOTAL</b>	<b>\$6,587</b>	<b>\$3.73 per ft²</b>
Home Performance (HP)		
Attic floor insulation, R60	\$4,402	R-60
Door weather stripping*	\$99	---
Lighting upgrades	\$387	17 units
Foundation floor insulation, R25	\$2,150	R-25
Seal envelope, typical*	\$831	ACH <sub>50</sub> 13 pre, 8.2 post
Local exhaust	\$917	---
Duct seal, typical*	\$849	CFM <sub>25</sub> 329 pre, 97 post
Low flow faucet*	\$19	1 unit
Drill and fill walls, R13	\$3,135	R-13
<b>TOTAL</b>	<b>\$12,789</b>	<b>\$7.23 per ft²</b>
Deep Energy Retrofit (DER)		
Roof insulation, R35	\$13,575	R-35
Door weather stripping*	\$99	---
Lighting upgrades	\$387	17 units
Foundation wall insulation, R18*	\$6,794	R-18
Seal envelope, aggressive*	\$1,246	ACH <sub>50</sub> 19.1 pre, 5.9 post
New Ducts	\$3,675	R-8
HRV	\$1,754	---
Low flow faucet*	\$19	1 unit
Drill and fill walls, R13	\$3,135	R-13
Exterior wall insulation, R16*	\$7,712	R-16
Gable wall insulation, R21*	\$796	R-21
Window replacement	\$14,746	U-value 0.32, 0.29 SHGC, 9 units
<b>TOTAL</b>	<b>\$53,938</b>	<b>\$30.51 per ft²</b>

Archetypal projects created to find the lowest cost approaches for typical house (1,768 ft², 1-story, 1970's home). Costs predicted using random forest regression models for each individual measure, then assembled into prescriptive packages.

### Envelope upgrade packages:

1. None – no envelope or HVAC upgrades
2. Weatherization (Wx) – typical for DOE Wx program
3. Home Performance (HP) – typical for a home performance contractor
4. Deep Energy Retrofit (DER) - typical high performance envelope

### Equipment (HVAC & DHW):

1. Gas
2. Gas + cooling (Air Conditioning)
3. All Electric

### PV :

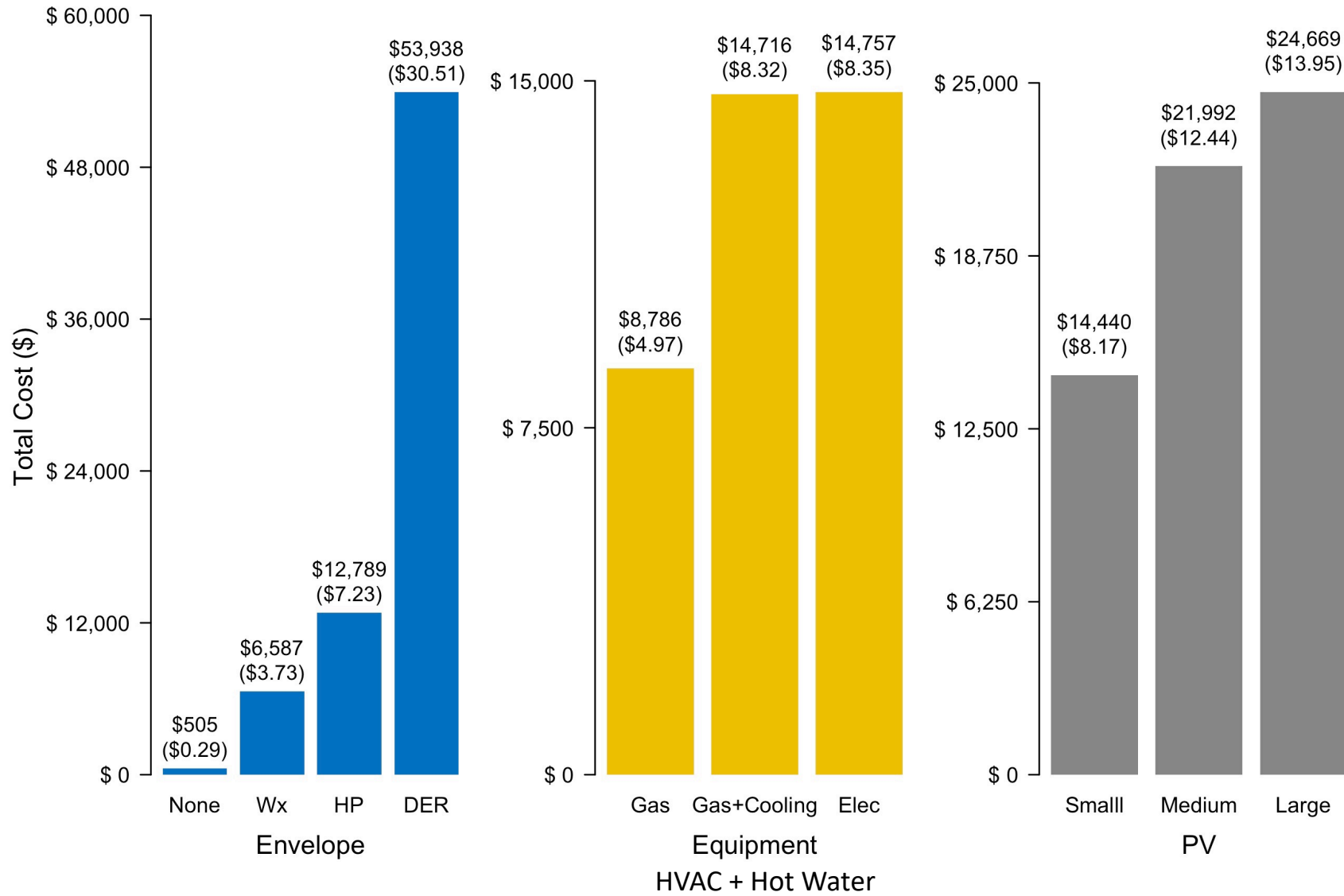
1. Small
2. Medium
3. Large



# Cost Compression – Package Optimization

## Archetypal Upgrade Packages

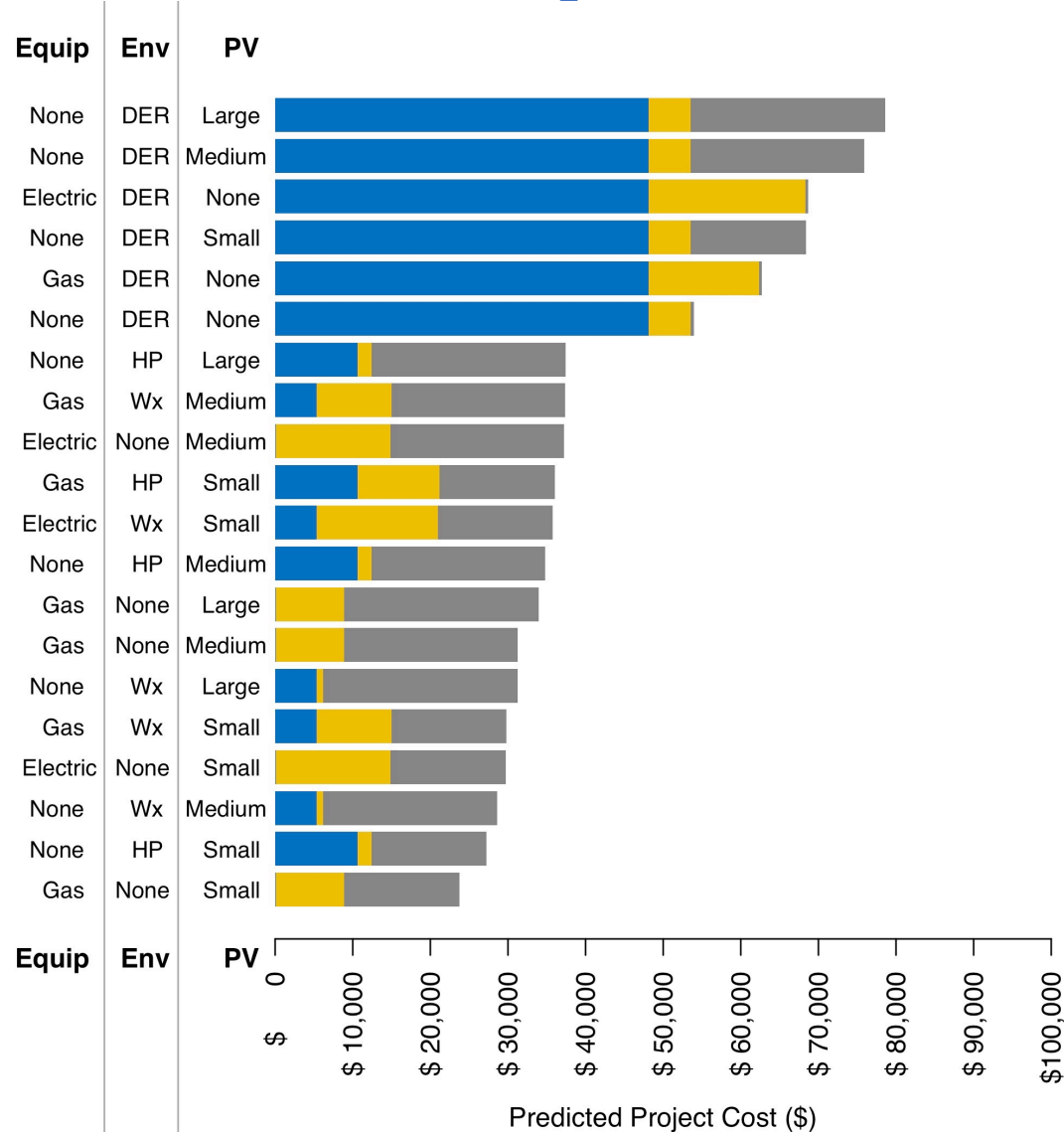
4 envelope, 3 HVAC & DHW and 3 PV options permuted to look for optimum solutions



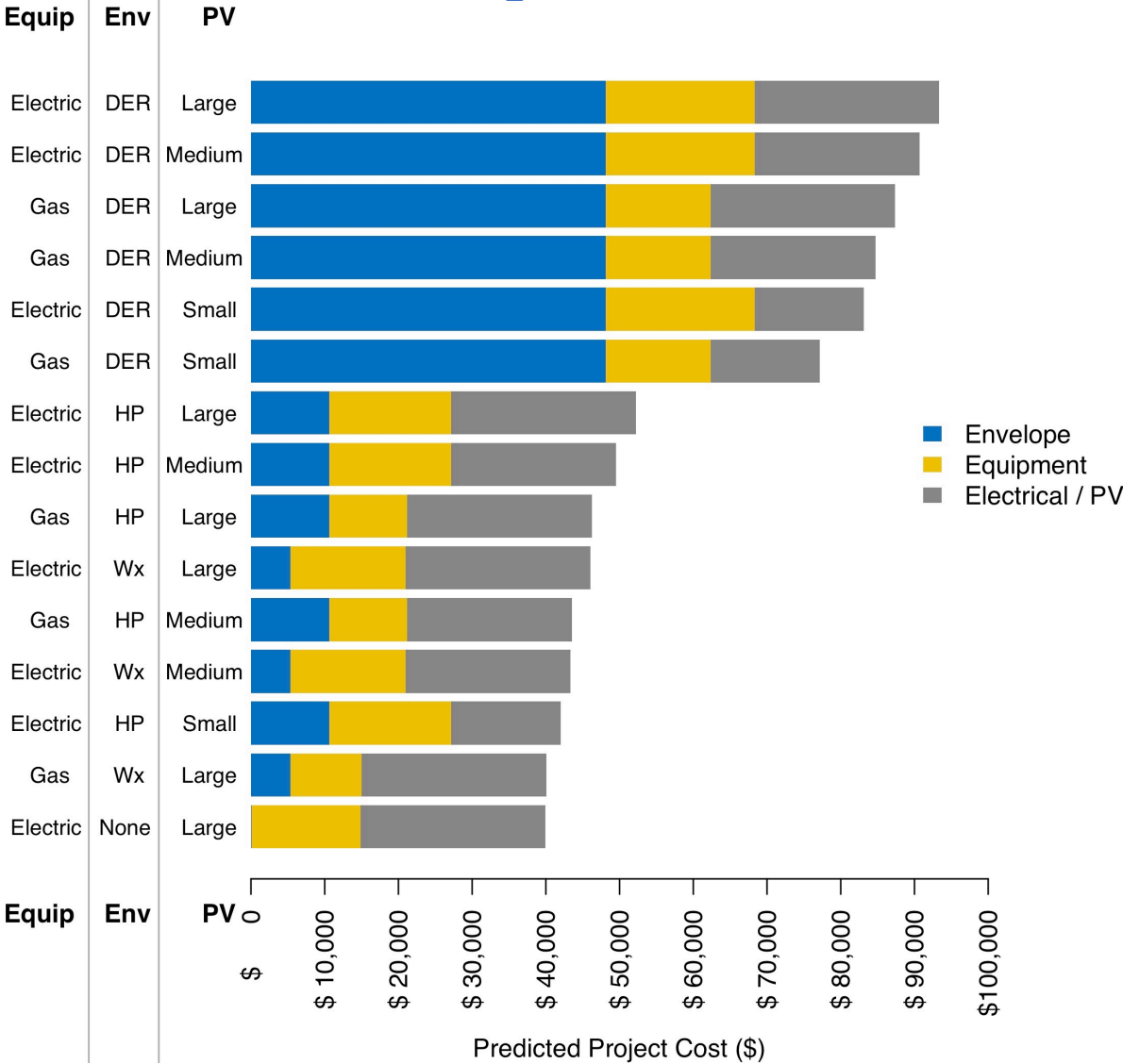
# Cost Compression – Package Optimization

## Archetypal Upgrade Packages

### 50-60% CO<sub>2</sub>e Savings

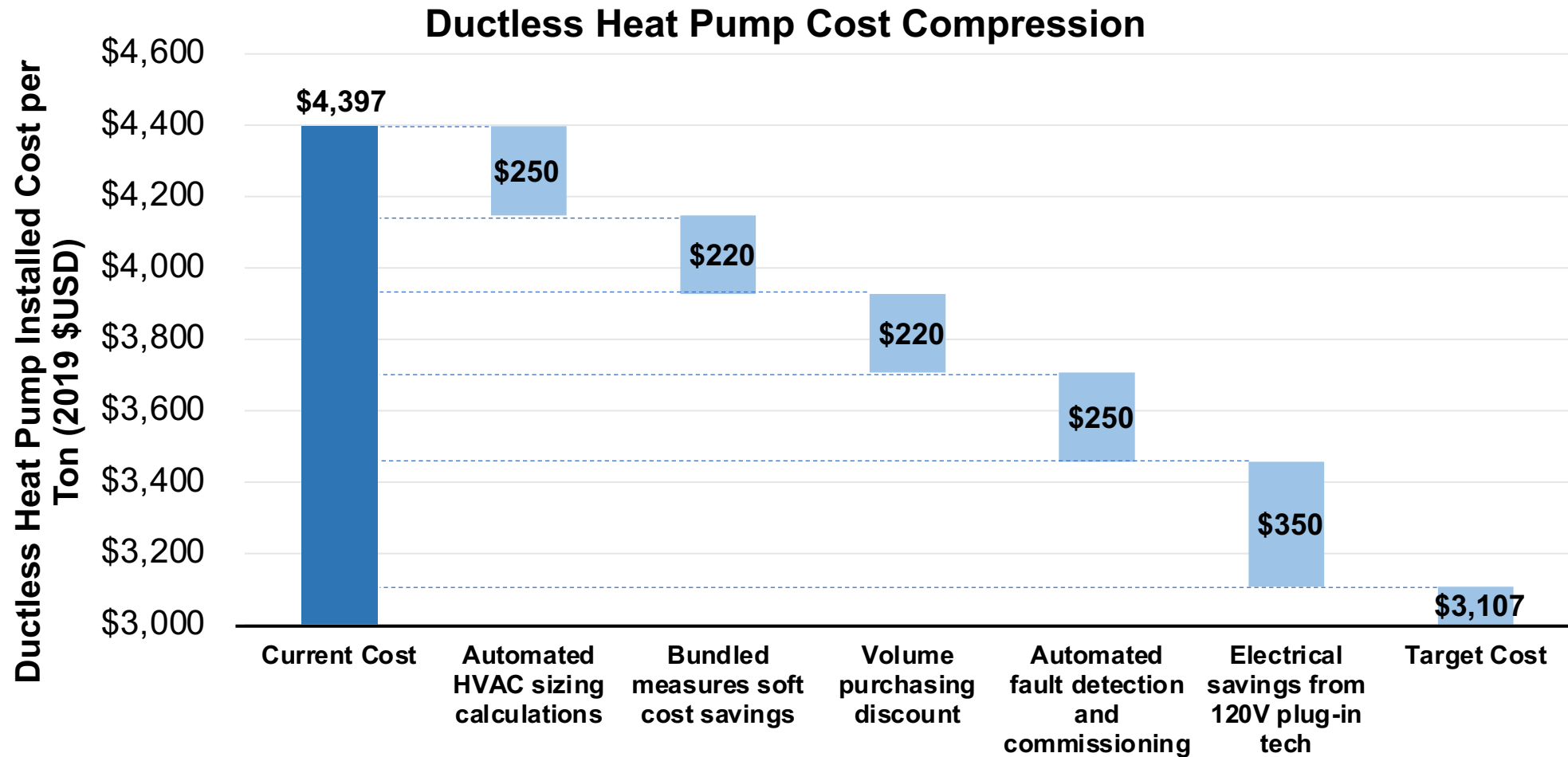


### 60-70% CO<sub>2</sub>e Savings

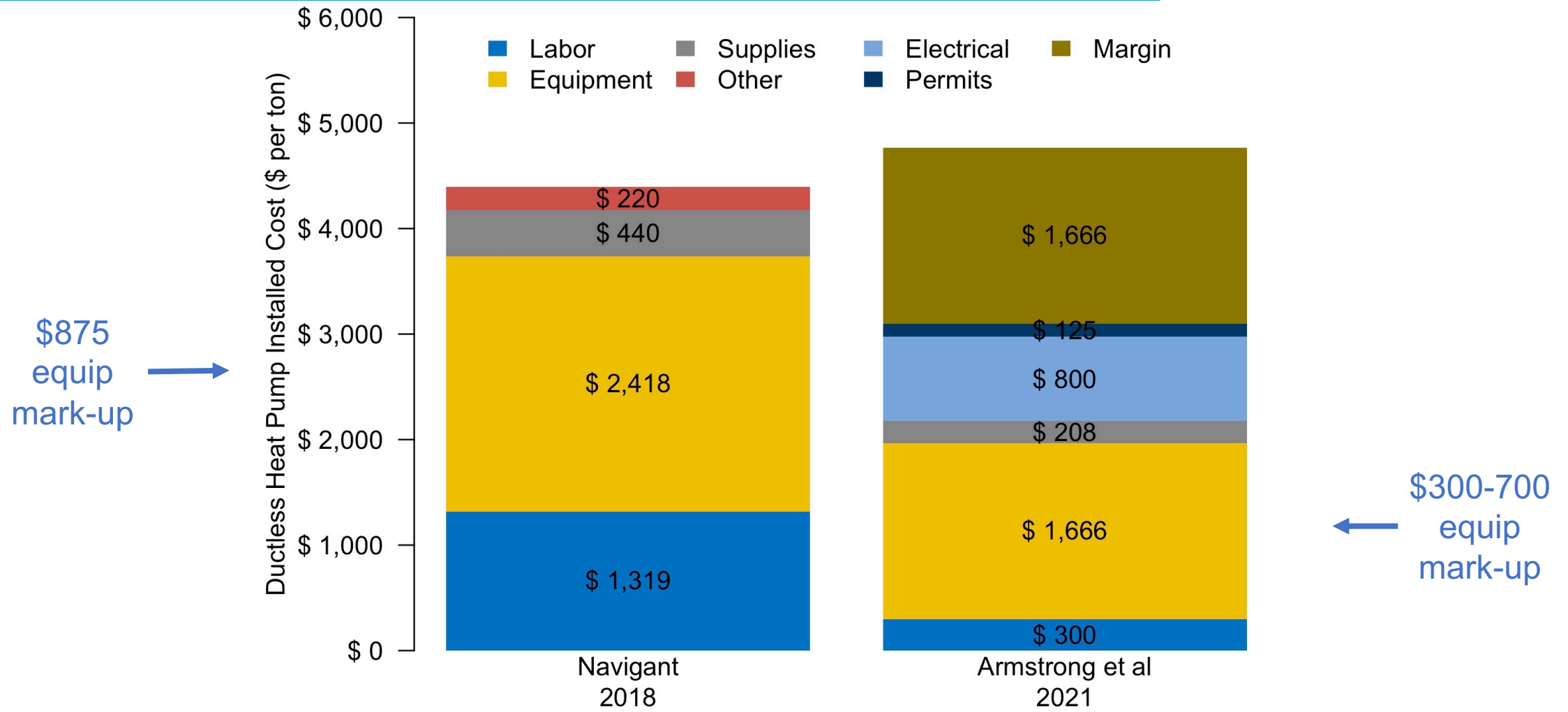


Carbon savings and costs predicted by regression models

# Cost Compression – Ductless Heat Pumps



# Cost Compression – Ductless Heat Pumps

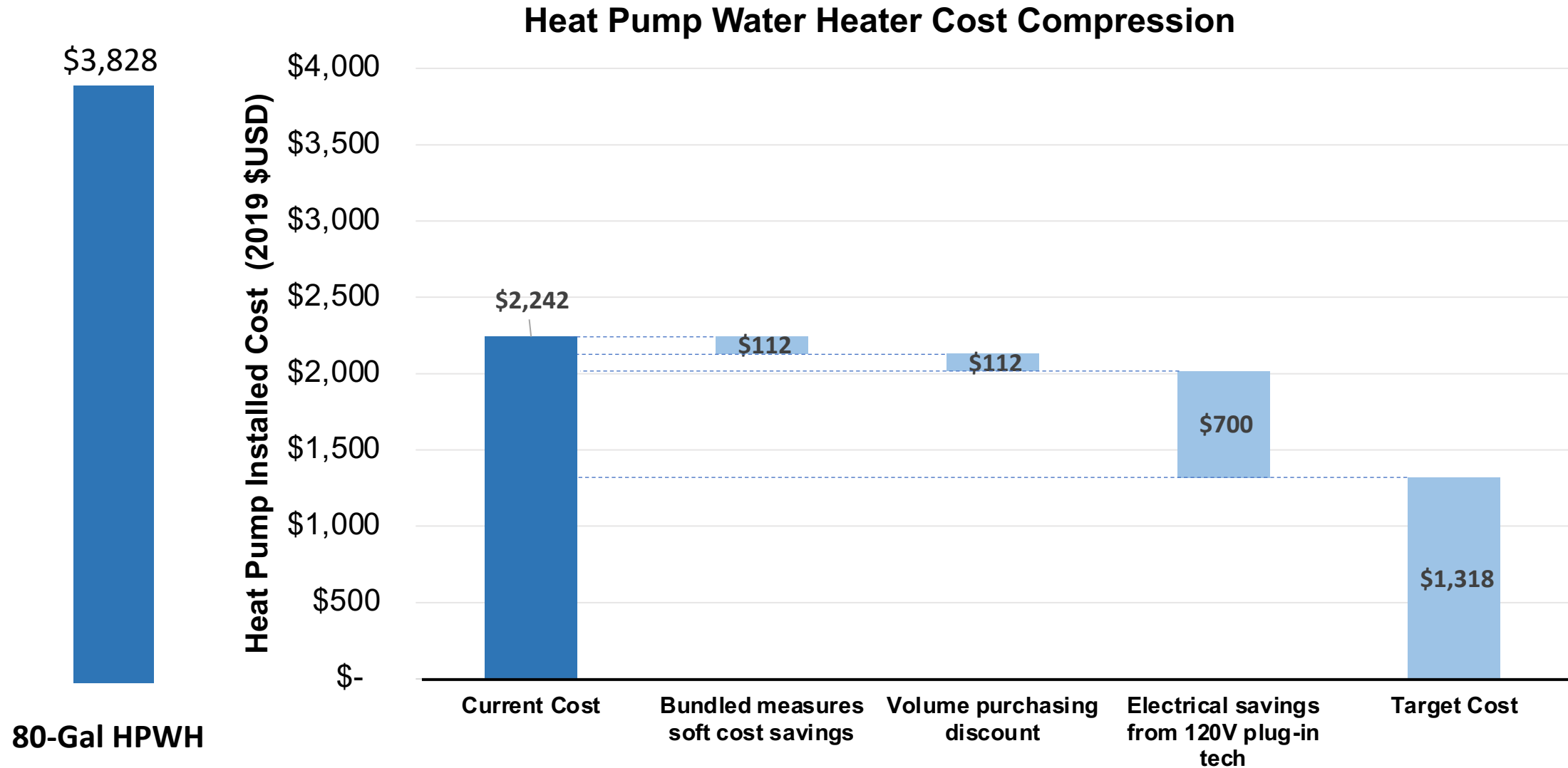


[https://ma-eeac.org/wp-content/uploads/RES28\\_Assembled\\_Report\\_2018-10-05.pdf](https://ma-eeac.org/wp-content/uploads/RES28_Assembled_Report_2018-10-05.pdf)

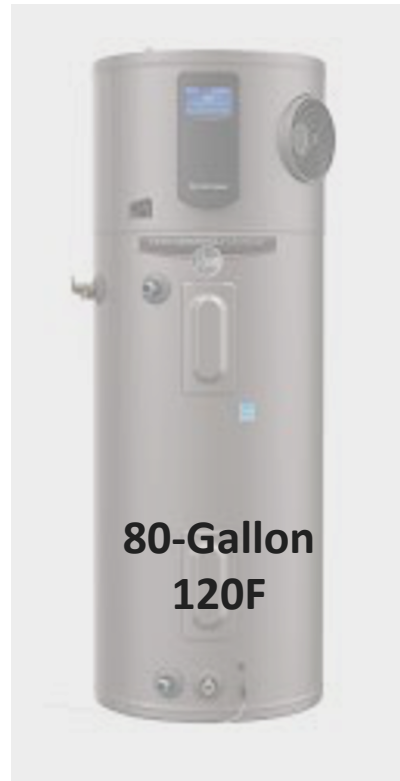
<https://www.redwoodenergy.tech/wp-content/uploads/2020/04/SF-Guide-4-10-2020.pdf>



# Cost Compression - Heat Pump Water Heater, 50-Gal



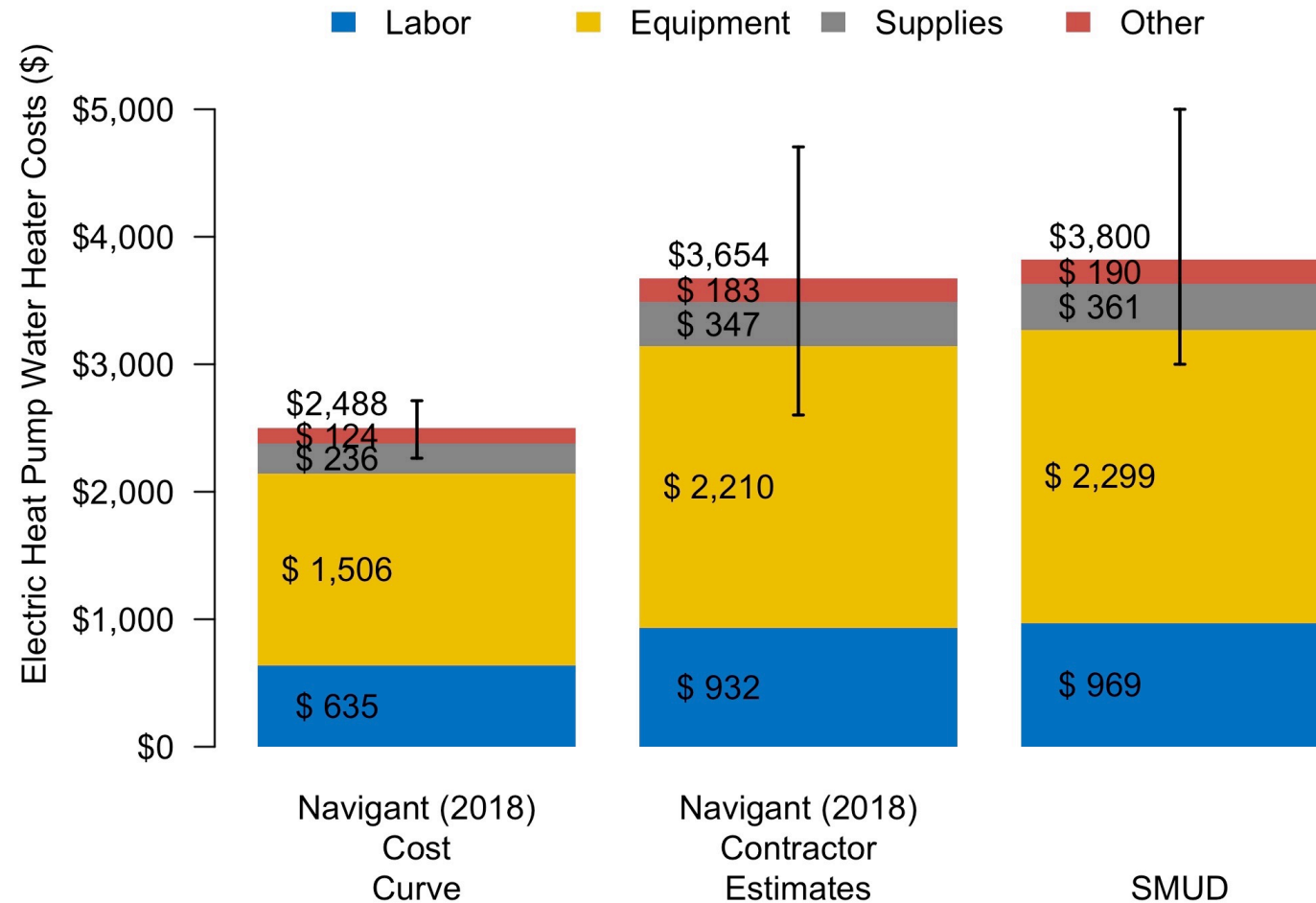
# Cost Compression - Heat Pump Water Heater, 50-Gal



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# Cost Compression - Heat Pump Water Heater



# Cost Compression – Low Power Electrification

## Avoiding Panel Upgrade Costs

**Contractor's Pricing Guide:**  
**Residential Repair & Remodeling Costs**  
with RSMeans data

\$1,954

Average range: **\$1,500 - \$4,000**



(replace an existing panel with a new model with new housing)

<https://www.fixr.com/costs/install-electrical-circuit-panel-upgrade>



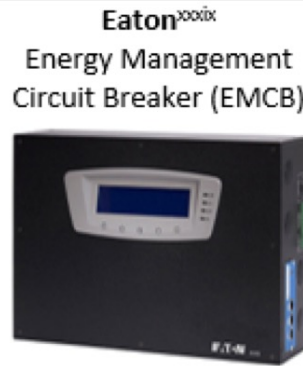
# Cost Compression – Low Power Electrification

## Avoiding Panel Upgrade Costs




### Smart Circuit Splitters and Sharing



### Programmable Subpanels



### Power-efficient Appliances (120V)

4.5 cu ft Condensing Washer/Dryer Combo	Heat Pump Water Heater	Through-Wall Heat Pump
10A, <b>1200W</b>	8.3A, <b>1000W</b>	6.3-15A, <b>~1400W</b>
LG WM3998HBA	GE GeoSpring	Innova HPAC 2.0
		

### Watt Diet Calculator

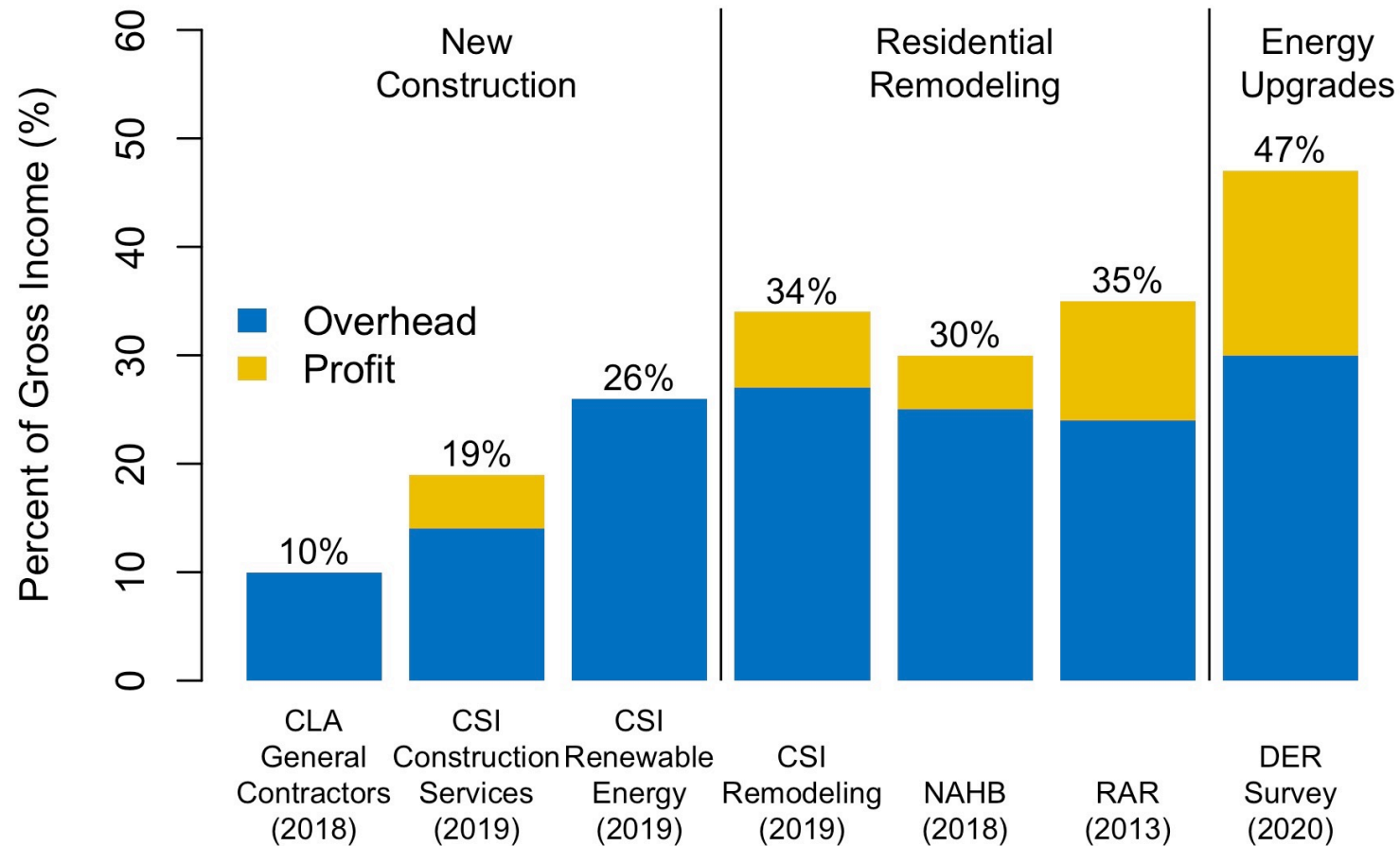
All Electric 100 Amp Home (2,000 square feet)

Ducted heat pump, medium power heat pump water heater, hybrid heat pump dryer

Device Volts	Device Amps	100 Amp Panel		Device Amps	Device Volts		
120	8	Lights/Plug	15	15	Lights/Plug	8	120
120	8	Lights/Plug	15	15	Lights/Plug	8	120
120	8	Lights/Plug	15	15	Lights/Plug	8	120
120	10	Garbage Disposal	20	20	Kitchen Outlets	13	120
120	7	Refrigerator	20	20	Kitchen Outlets	13	120
120	0	Spare	15	20	Dishwasher	12	120
120	0	Furnace (removed)	15	20	Clothes Washer	13	120
240	20	Heat Pump Centrally Ducted	30	20	Hybrid Heat Pump Dryer	14	240
240	20	EV Charger	25	50	Range (cooktop +oven)	40	240
240	16	Solar Input	20	20	Heat Pump Water Heater	12	240
House square footage = 2000		Total Counted Panel Amps = 96.7					



# Cost Compression – Soft Costs



## Need to reduce Soft Costs:

- Customer acquisition
- Testing
- Program participation
- Load calculations
- Project design

# Cost Compression – Soft Costs

	Outsource customer acquisition to programs with marketing and sales expertise	Reduce diagnostic testing and commissioning	Remote approaches to customer acquisition, management and sales	Automated, rapid HVAC equipment sizing
CURRENT	\$1,000-2,500 per project	Combustion: \$387	Remote audits: 40% cost savings for individual projects	\$564
COMPRESSED	\$700	\$0	60% savings for executed projects	\$100

# Cost Compression – Soft Costs – Real Life Examples DIY Solar PV

- Eliminate overhead with online experience
- Flat pricing across the US
- DIY or full-service options

**Want to DIY? You put up the panels, we do the rest.**



PROJECT SOLAR BLOG FAQ CONTACT

## Forget Everything You've Heard About Solar

Same Equipment. Same Warranty. **Lowest Price.**

GET STARTED

## Transparent Pricing Lowest Guaranteed

	OPTIONAL ADD ONS	
<b>Equipment</b> + Permits & DIY Support <b>\$0.90-\$1.20 /watt</b> GET STARTED WITH EQUIPMENT	+	<div><b>Ground Mount</b> + Installation <b>\$0.30* /watt</b> GET STARTED WITH GROUND MOUNT</div> <div>OR</div> <div><b>Full Service Install</b> + Warranty <b>\$0.37* /watt</b> GET STARTED WITH FULL SERVICE</div>

\*Pricing reflected as after incentive pricing.

# Cost Compression – Soft Costs – Real Life Examples



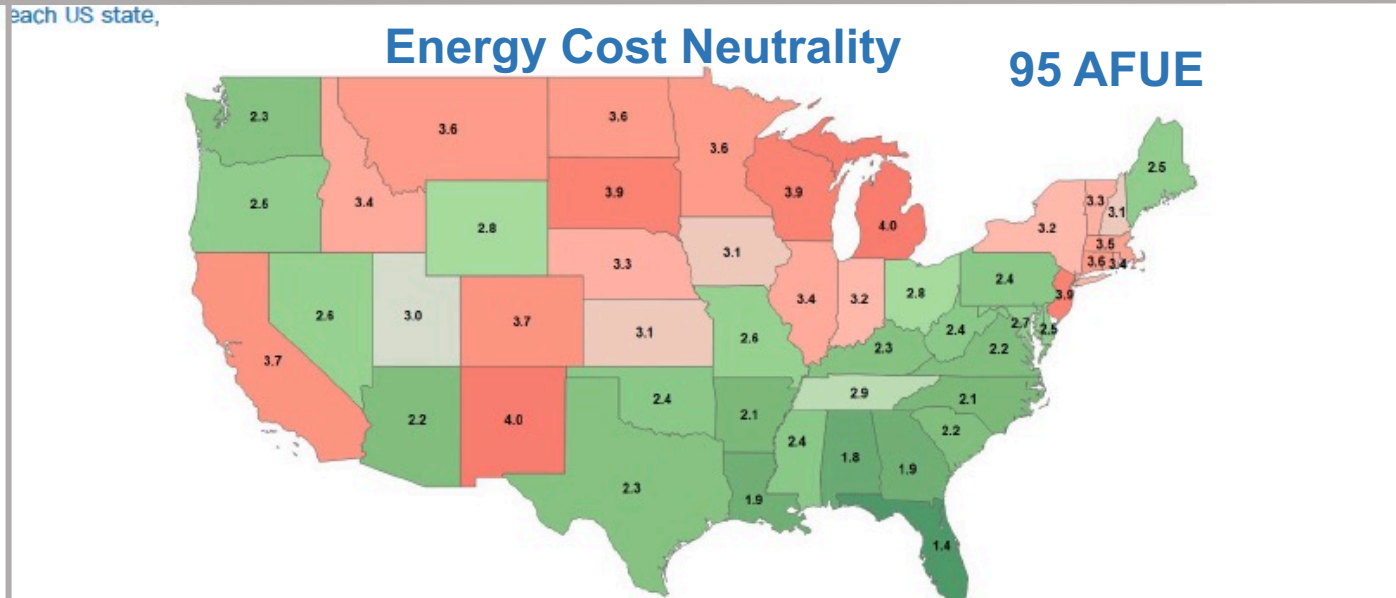
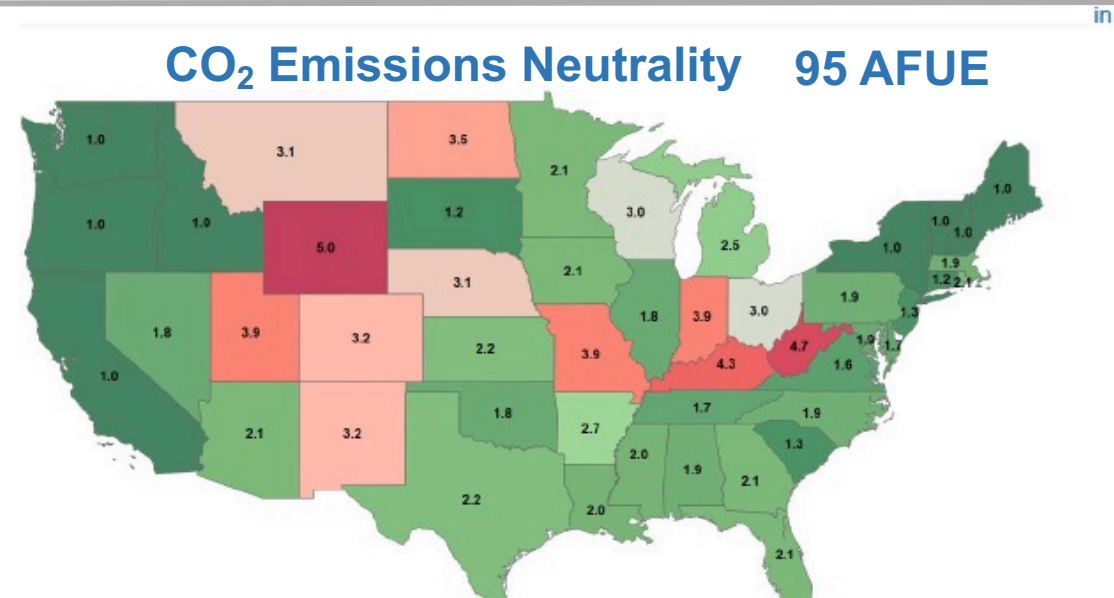
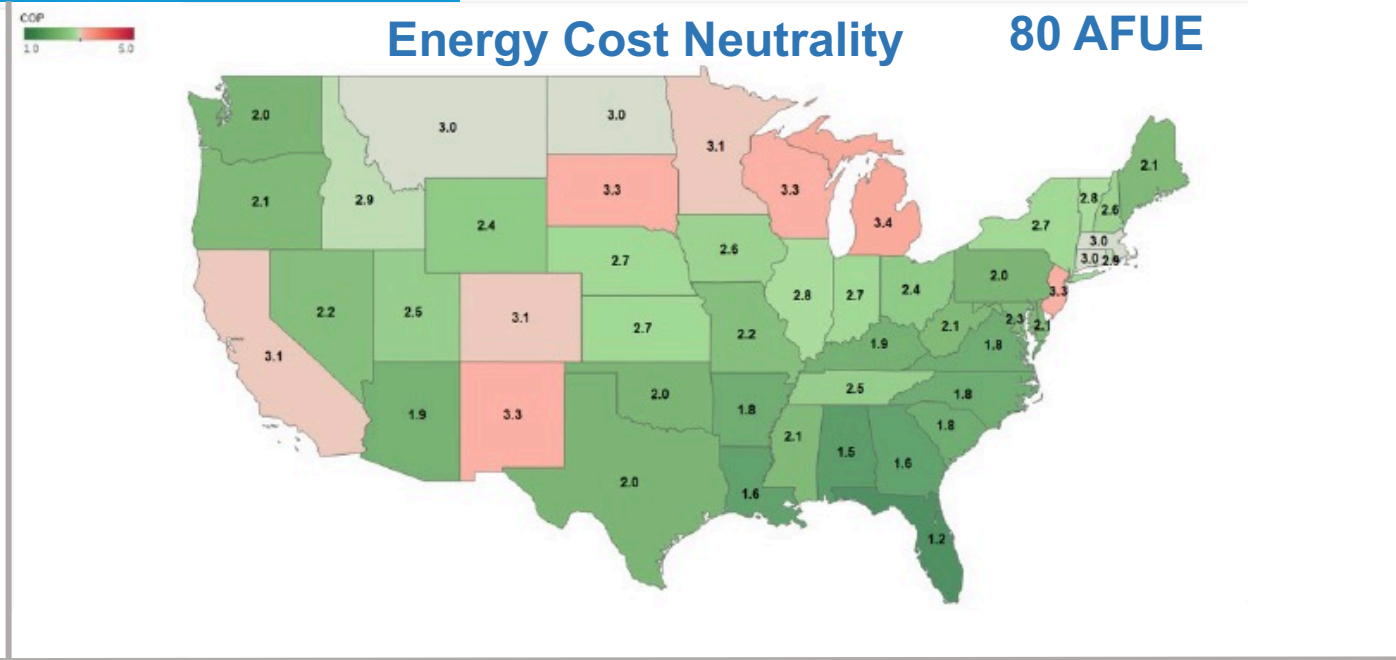
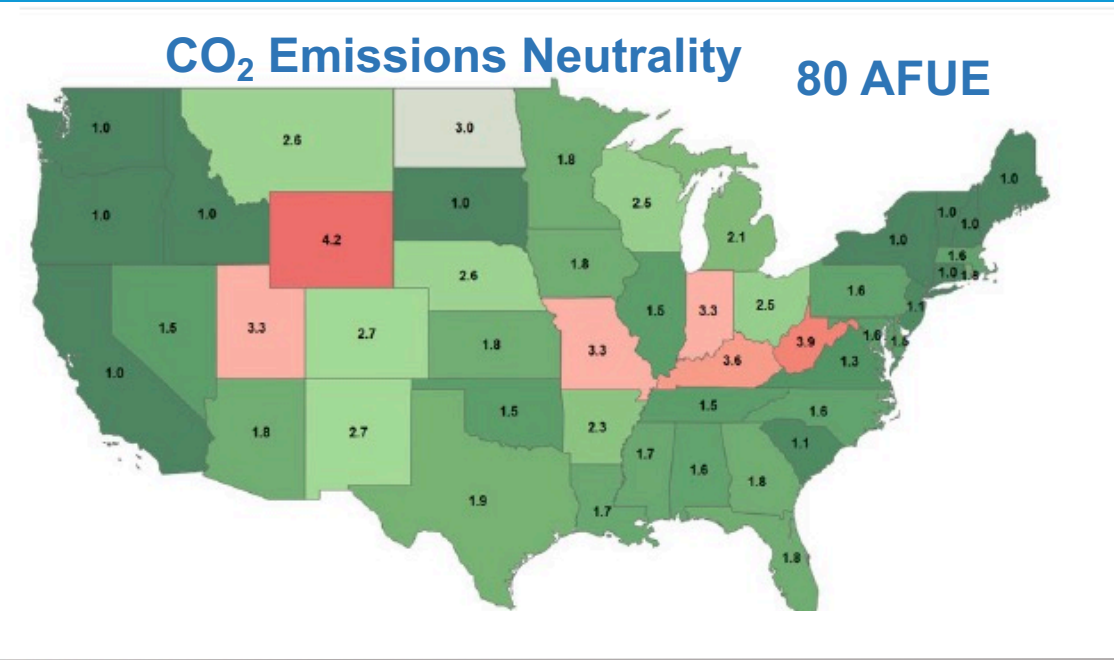
DIY/very simple install:

- Custom design
- Pre-insulated line sets
- Simplified fittings
- Strong advertising

# Decarbonization Costs – New Metrics

Using Electric Heat Pumps Instead Of Gas Furnaces

Heat Pump COP required to break even with a gas furnace



in each US state,



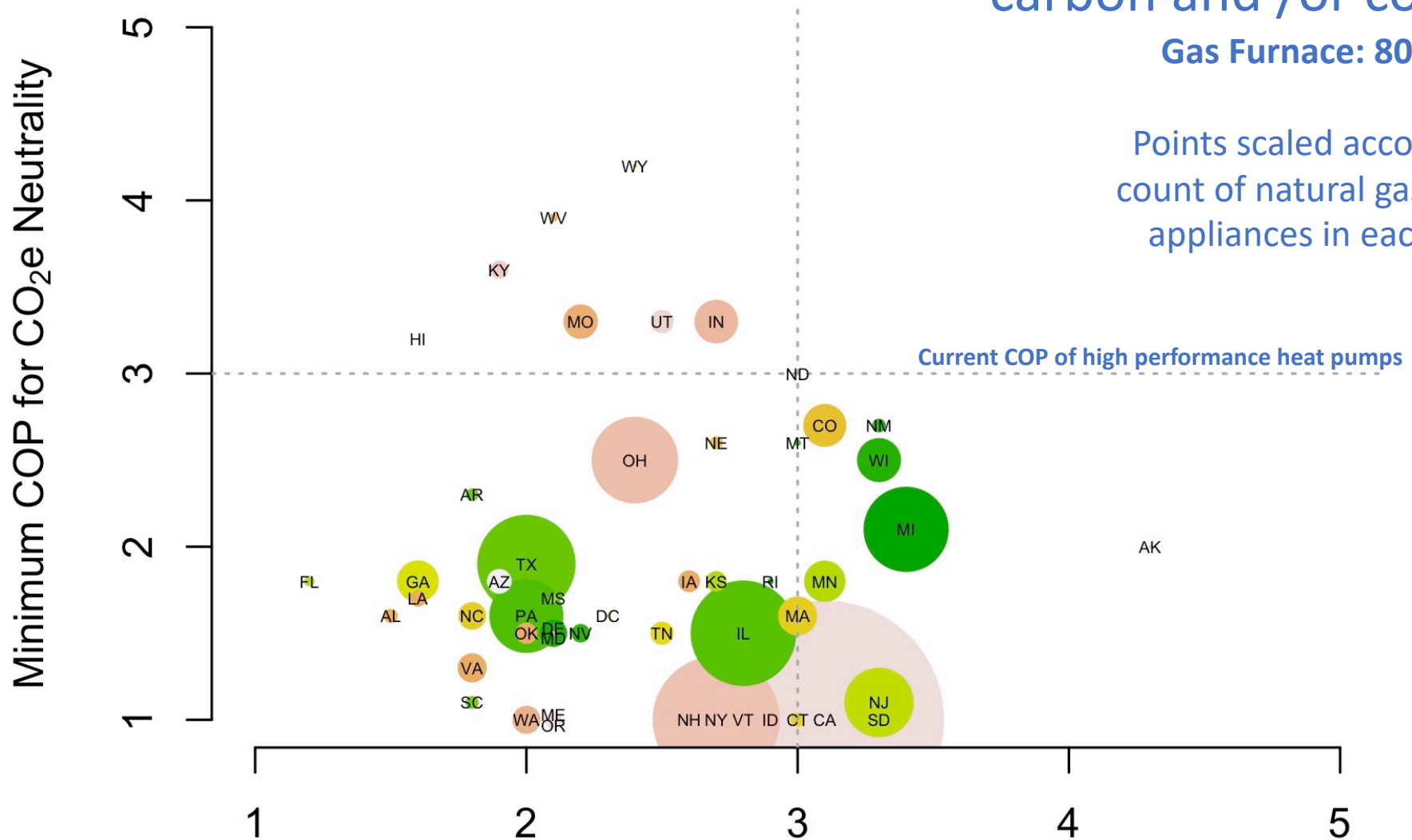
# Decarbonization Costs— New Metrics

Using Electric Heat Pumps Instead Of Gas Furnaces

What Heat Pump performance is required to be carbon and /or cost neutral?

Gas Furnace: 80 AFUE

Points scaled according to count of natural gas heating appliances in each state



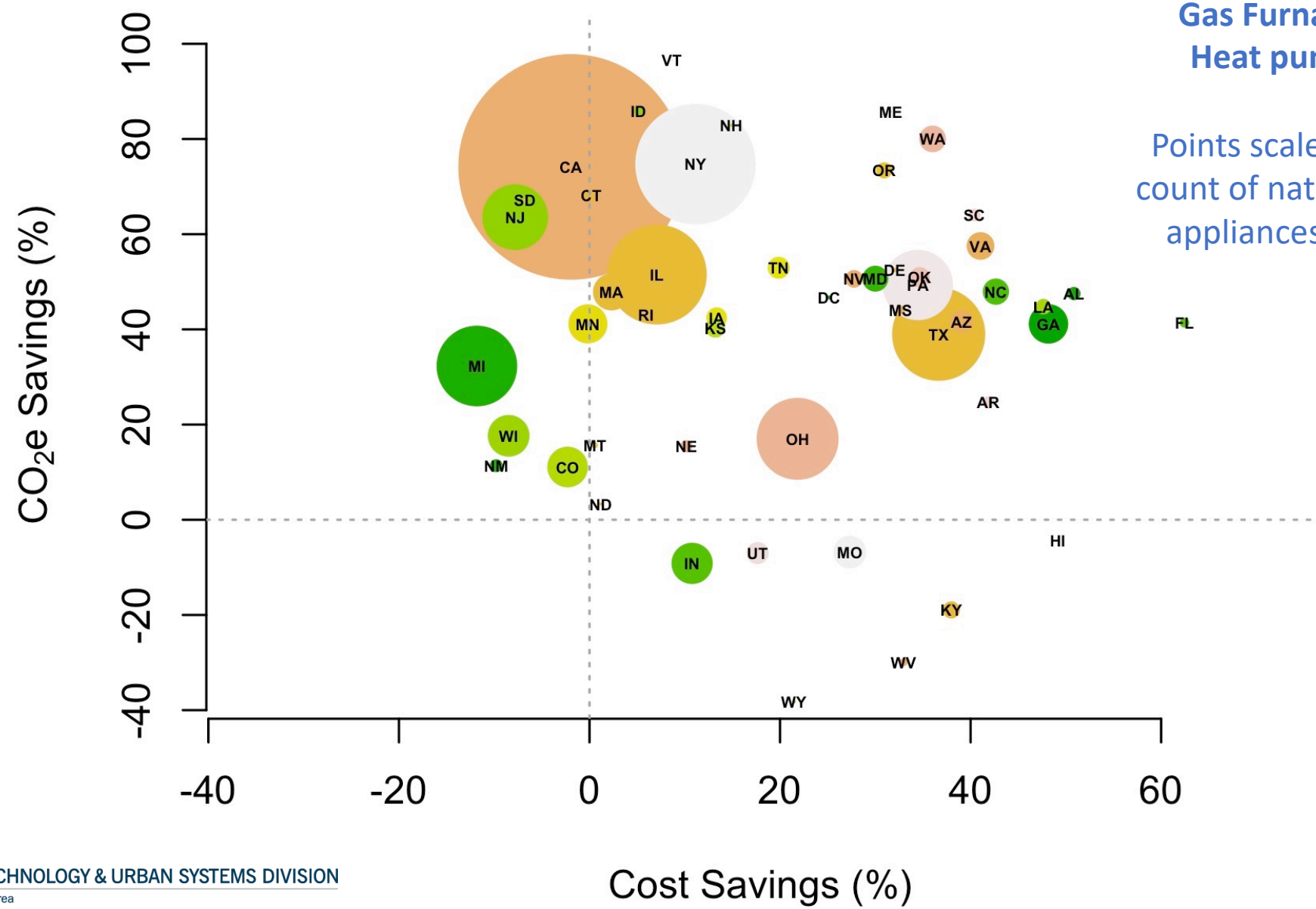
# Cost Compression – New Metrics

Using Electric Heat Pumps Instead Of Gas Furnaces

What are the carbon and cost savings?

Gas Furnace: 80 AFUE  
Heat pump: 3.0 COP

Points scaled according to count of natural gas heating appliances in each state



# Cost Compression – No- and Low-Cost

## Automated emission reductions



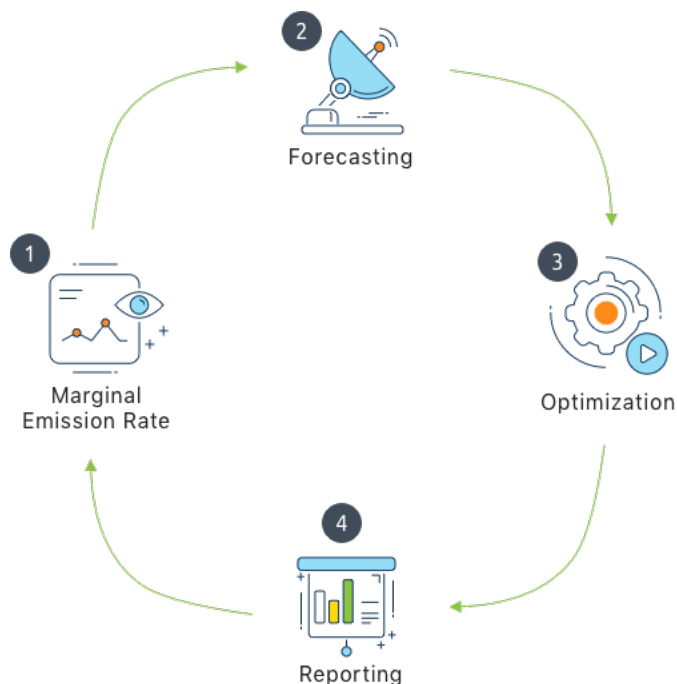
Small – but easy and low cost  
Should be part of every project



HOMEintel

"We cut our bill in half and are on track to save over \$2,000 after the changes we made with HomeIntel's help."

HomeIntel customer



**Their story:** This couple has lived in their 3,000sqft home in Stanford, CA for 30 years.

Despite completing HVAC upgrades, they still had high energy use.

**Their results:** Saving \$220 per month and over \$2,500 annually.



The customer above found **4 Energy Hogs** using HomeIntel.



(1) Old **baseboard heaters** costing \$100 per month



(2) Continuous hot water **recirculation pump** costing \$50 per month



(3) 20 year old **wine cellar** (cooler pictured) costing \$120 per month



(4) Instant **hot water dispenser** under the sink costing \$30 per month



BUILDING TECHNOLOGY & URBAN SYSTEMS DIVISION

Energy Technologies Area

# What's Next?

- Cost Compression
  - Financing – reduce “sticker shock”
  - Technology – affordable, low-power HVAC/DHW/Cooking/clothes dryer appliances
  - Soft Costs
    - Streamlining/Reducing installation, code and permitting requirements
    - Standardized packages of upgrades to simplify decision-making process
- Electrification for Low-Income households
  - Drop-in/Plug-in/DIY approaches
  - Transportable technologies
- How to overcome emergency equipment replacement – make lower carbon the lowest cost default option

# References

Chan, W. R., Less, B. D., & Walker, I. S. (2021). *DOE Deep Energy Retrofit Cost Survey*. Lawrence Berkeley National Laboratory. <https://doi.org/10.20357/B7MC70>

Less, B. D., Walker, I. S., & Casquero-Modrego, N. (2021). *Emerging Pathways to Upgrade the US Housing Stock: A Review of the Home Energy Upgrade Literature*. Lawrence Berkeley National Lab. <https://doi.org/10.20357/B7GP53>

Less, B. D., Walker, I. S., Casquero-Modrego, N., & Rainer, L. (2021). *The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes*. Lawrence Berkeley National Laboratory. [https://eta-publications.lbl.gov/sites/default/files/final\\_walker\\_-\\_the\\_cost\\_of\\_decarbonization\\_and\\_energy.pdf](https://eta-publications.lbl.gov/sites/default/files/final_walker_-_the_cost_of_decarbonization_and_energy.pdf)